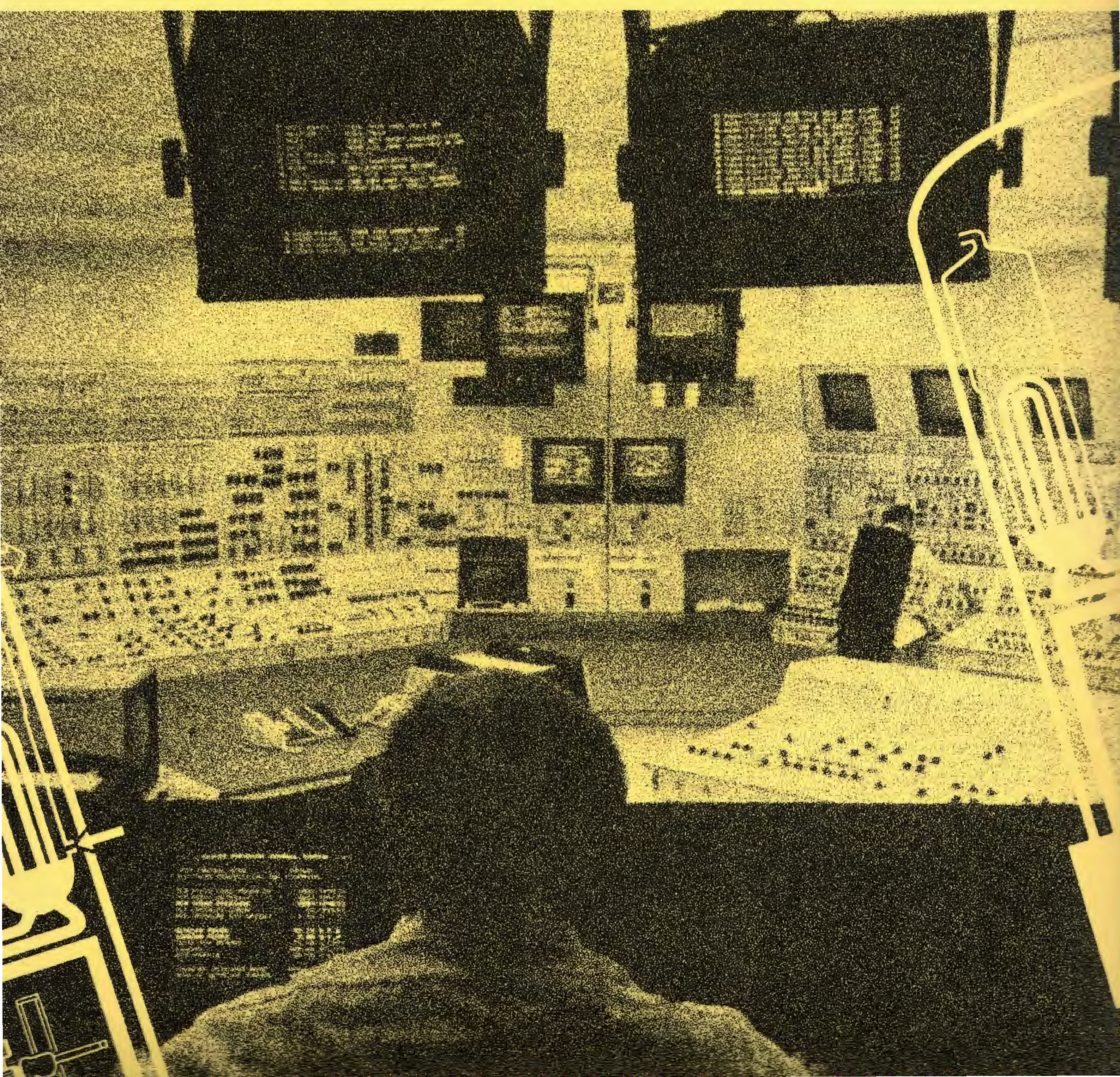
A Journalist's Guide to Nuclear Power



Acknowledgement

We are grateful to Atomic Energy of Canada Limited (AECL) for modifying a number of illustrations from their *Technical Summary: CANDU Nuclear Generating Station* for our use.

Many people in Ontario Hydro have contributed material to this handbook. The organization's support of this publication has been excellent and much appreciated.

Special mention must be made of those departments whose contributions of time and material were essential and substantial:

Nuclear Studies and Safety Department;
Health Physics Services Department;
Electrical Research Department;
Central Nuclear Service
Business Administration Department;
Nuclear Materials Management Department;
Central Nuclear Training Department.

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Media Relations
Ontario Hydro

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Introduction

Unfortunately, providing unbiased factual information to the public often takes second place to propagating opinions. Too often, anti-nuclear activists rely on emotion; too often, nuclear advocates rely on bland reassurance.

—Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, December, 1985.

Ontario Hydro can't plausibly claim neutrality in the debate over nuclear-electrical power. But this guidebook is not intended to be part of the debate. Rather, it's meant to assist in communicating information about nuclear matters.

We have tried to provide answers to the kinds of questions we are asked, or are likely to be asked, on a day-to-day basis and during times of intense media interest, like those following an accident at a nuclear plant. We canvassed a number of reporters for suggestions and most of their ideas have been incorporated in this guide.

This *Journalist's Guide* was compiled by Michele McMaster, a media relations officer in Hydro's Corporate Communications Department, with the help of technical experts in a number of areas. The job of the media relations group is to supply information to the media fully, accurately and promptly, so the media and the public understand what Ontario Hydro does and why it does it. This book is part of that effort.

Robertson Cochrane
Manager, Corporate Communications

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The CANDU Reactor

The acronym CANDU stands for Canada Deuterium Uranium.

The CANDU was developed in Canada with most of its parts being manufactured in Canada. All steps in the production of the uranium fuel used—from mining to fuel assembly—are carried out in Canada.

Deuterium oxide (D_2O), more cómmonly known as heavy water, is both the moderator and heat transport fluid. It controls the naturally-occurring fissions in Uranium-235 and draws the heat from the fuel to boil ordinary water into steam, turn the turbine generator and produce electricity.

Because heavy water is such an effective moderator, fuel goes into the CANDU containing the same proportions of the various isotopes found in natural uranium. Virtually every other reactor design in the world must enrich the fuel—upgrade the proportion of U-235.

Ontario Hydro's involvement in developing the CANDU dates, indirectly, from the earliest days at the Chalk River Nuclear Laboratories where engineers, some of whom would later join the utility, were studying the potential of uranium. As early as 1949, the Hydro Electric Power Commission of Ontario (now Ontario Hydro) became interested in the idea of nuclear fission for electricity generation. Beginning in 1954, the commission collaborated with Atomic Energy of Canada Limited (AECL) to develop the concept which became the CANDU.

Today, two large nuclear power stations, Pickering Nuclear Generating Station and Bruce Nuclear Power Development, supply almost half the electricity in the province and their reactors rank among the most reliable in the world (page 87). A third station, Darlington Nuclear Generating Station, is nearing completion. The following pages provide information about these stations.

Two small prototype CANDU stations, Douglas Point and Nuclear Power Demonstration (NPD), proved the viability of large-scale reactors. Both have since closed. Information on them is contained in the **Chronology**, beginning on page 81a.

Pickering Nuclear Generating Station

A Station†	Unit Size (MW)*	Date Construction Started	Date in Service	Cost ($ of Year)**	Cost (Constant $)***
Unit 1	542	1965	July 1971	$716 million††	$3.3 billion††
Unit 2	542	1965	Dec. 1971		
Unit 3	542	1967	June 1972		
Unit 4	542	1967	June 1973		
B Station					
Unit 5	540	1974	May 1983	$3.8 billion††	$4.5 billion††
Unit 6	540	1974	Feb. 1984		
Unit 7	540	1974	Jan. 1985		
Unit 8	540	1974	Feb. 1986		

† Units 1 and 2 have been completely retubed, after a pressure tube rupture in 1983. Unit 1 returned to service in September 1987, and unit 2 is expected back in the fall of 1988.

Retubing work on unit 3 will begin in 1989. Unit 4 will be retubed beginning in 1991, when unit 3 returns to service, and should take 19 months. While the units are operating well, their pressure tubes are aging more rapidly than anticipated and so the retubing schedule has been advanced (see page 37).

* Megawatts installed capacity (see **Glossary**).

** Dollars-of-the-year costs are the total of each year's costs during the construction period. There is no provision for inflation. This total is the most frequently used number when speaking of the cost of building a generating station.

The cost of retubing the A station is not included in this total. Retubing units 1 and 2 cost $450 million (dollars of the year, 1984-1988) and work on the last two units is expected to cost about $500 million in dollars of the year, 1989-1993.

*** Constant dollars costs factor in inflation, to indicate what it would cost to build the plant now, based on the purchasing power of a dollar on December 31, 1987.

†† Includes heavy water inventory and commissioning costs.

Pickering Nuclear Generating Station

Location:
On Lake Ontario, in the town of Pickering, 40 kilometres (25 miles) east of Toronto.

Size of Site:
271 hectares (670 acres).

Staff:
1,500.

On Site:
Pickering A and B generating stations, four CANDU reactors each, one vacuum building common to the eight reactors.

The Eastern Nuclear Training Centre trains control room operators and trades staff for Pickering A and B and Darlington. Computerized control room simulators used for first operator training are located here.

Construction Services Division, which is responsible for all construction done in the province by Hydro, except Darlington, is located at the Pickering site.

Information Centre: Each year, about 20,000 visitors tour the information centre and an additional 25,000 learn about nuclear power through Pickering's outreach program.

Wildlife sanctuary/recreation area, 20 hectares (50 acres) in size.

Associated Facilities:
Fish Farm: Located at the edge of the Pickering site, the farm is owned by Cool Water Farms and run by Limnos Ltd. Up to 45,460 litres (10,000 gallons) of slightly warmed water from Pickering's condensor cooling system passes through the fish tanks each day. In 1987, the farm produced yellow perch, trout and American eels.

Contact:
Jack Muir
Community Relations Officer
(416) 839-1151, ext. 3185.

Darlington Nuclear Generating Station

	Unit Size (MW)*	Date Construction Started	Date in Service	Cost ($ of Year)**	Cost (Constant $)***
Unit 1	935	1982	1989	$11.2 billion††	$11.2 billion††
Unit 2	935	1981	1990		
Unit 3	935	1985	1991		
Unit 4	935	1986	1992		

* Megawatts installed capacity (see **Glossary**).

** Dollars-of-the-year costs are the total of each year's costs during the construction period—there is no provision for inflation. This total is the most frequently used number when speaking of the cost of building a generating station.

*** Constant dollars costs factor in inflation to indicate what it would cost to build the plant now, based on the purchasing power of a dollar on December 31, 1987.

†† Includes costs of heavy water inventory, commissioning, capitalized training and half the reactors' initial fuel.

Bruce Nuclear Power Development

Location:
On Lake Huron, between Kincardine and Port Elgin, 256 kilometres (160 miles) northwest of Toronto.

Size of Site:
930 hectares (2,300 acres); plus 450-hectare (1,112-acre) buffer zone, 405-hectare (1,000-acre) Bruce Energy Centre, 265-hectare (655-acre) Inverhuron Park.

Staff:
3,500.

On Site:
Bruce A and B generating stations, four CANDU reactors each, one vacuum building for each four-unit station.

Heavy Water Plant B: This plant produces heavy water for Hydro's reactors. Energy for the plant is supplied by steam from the reactors at Bruce A (see note opposite). The process of making heavy water is explained on page 68.

Construction began on Heavy Water Plant B in 1974 with startup in 1981. Plant B was built at a cost of $1.2 billion. It should be noted, however, that rolled into that are the costs of plants C and D, which were cancelled because of lower-than-forecast demand for heavy water. Plant D was half finished when it was mothballed in 1979. Plant C was cancelled early in its construction, in 1976.

The first plant, plant A, was built by AECL to supply the Canadian reactor and research program. It began production in June 1973 and was bought by Hydro in July of the same year. The plant was mothballed in 1984 when capacity exceeded demand and it was decided to keep the newer plant operating.

Before there was a domestic supply of heavy water, Canada bought it from the United States, Sweden and the Soviet Union.

Steam plant: an oil-fired plant which can be used if steam production from the Bruce A reactors is inadequate for the needs of the Heavy Water Plant and the Bruce Energy Centre.

Waste storage: low and medium level radioactive waste storage facilities for all Hydro's stations are at Bruce.

Western Nuclear Training Centre trains control room operators and trades staff for Bruce A and B and the Heavy Water Plant. Computerized control room simulators, used for first operator training, are located here.

Central Maintenance Facility for the site is housed in its own building.

Douglas Point, a 220-megawatt prototype CANDU reactor, is also on site. It was closed in 1984 and has been partly decommissioned. The station was on Hydro land and was operated by Hydro, which bought the electricity from the station owner, AECL. Since the station was closed, AECL has bought the land and Hydro has no further role in its maintenance.

Information Centre: 35,000 visitors tour the centre each year.

Associated Facilities:
The Bruce Energy Centre is located across the road from the nuclear power development. It is an industrial park where greenhouses and factories run on process steam from the Bruce A reactors (see note under chart opposite).

Inverhuron Park is adjacent to the Bruce site. Hydro leases it to the province for a nominal fee. It is a day-use-only park.

Community Impact Payments:
A total $1.8 million in community impact payments has been paid to the nine communities around the site and to Bruce County, the Bruce County Board of Education and the Bruce-Grey Separate School Board. Grants in lieu of taxes, amounting to $475,000, are paid annually to Bruce Township; $1 million over five years will be paid to the South-Bruce Lakeshore Economic Development Corporation to help market the Bruce Energy Centre. Hydro is involved indirectly in other programs to assist local communities in tourism and real estate promotion.

Contact:
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Bruce Nuclear Power Development

A Station†	Unit Size (MW)*	Date Construction Started	Date in Service	Cost ($ of Year)**	Cost (Constant $)***
Unit 1	815	1970	Sept. 1977	$1.8 billion††	$5 billion††
Unit 2	825	1970	Sept. 1977		
Unit 3	815	1970	Feb. 1978		
Unit 4	815	1970	Jan. 1979		
B Station†					
Unit 5	890	1976	Nov. 1984	$5.9 billion†††	$6 billion†††
Unit 6	890	1976	Sept. 1984		
Unit 7	890	1976	April 1986		
Unit 8	890	1976	May 1987		

† Each Bruce A reactor is designed to produce more steam than its turbine can turn into electricity. The reactors' total steam production, expressed in equivalent electrical megawatts, is 904 megawatts per reactor. The extra steam is used to heat the Western Nuclear Training Centre, the Central Maintenance Facility, the Bruce Energy Centre and the Heavy Water Plant. If full steam production is not needed, the reactor power is lowered, so that steam production matches turbine capacity.

The turbines at Bruce A and B are larger than necessary for the size of the reactors. Modifications to the boilers have increased the steam pressure so that the turbine capacity can be more fully used and the units can produce more electricity than the reactor size would indicate. The Bruce A turbine generators are currently being operated at 825 megawatts each. They were originally rated at 740 megawatts. The B station turbine generators have been able to produce up to 930 megawatts and will likely be uprated. To increase the electrical production of a unit, AECB permission and that of the Ministry of Consumer and Commercial Relations (which has responsibility for all boilers in Ontario) is needed.

At present, there are two 230-kilovolt transmission lines and one 500-kilovolt transmission line from the Bruce Nuclear Power Development. Since these lines are insufficient to transport all the electricity produced at the station, the electrical output of the reactors must be scaled back to 5,400 megawatts. Construction of a second 500-kilovolt line has been reviewed by the Joint Hearing Board, approved by the provincial government and is expected to be in service in August 1990.

* Megawatts installed capacity (see **Glossary**).

** Dollars-of-the-year costs are the total of each year's costs during the construction period—there is no provision for inflation. This total is the most frequently used number when speaking of the cost of building a generating station.

*** Constant dollars costs indicate what it would cost to build the plant now, based on the purchasing power of a dollar on December 31, 1987.

†† Includes heavy water inventory and commissioning costs.

††† Includes costs of heavy water inventory, commissioning, capitalized training and half the initial fuel in the reactor.

Darlington Nuclear Generating Station

Location:
On Lake Ontario, southwest of Bowmanville, in the Town of Newcastle, 75 kilometres (47 miles) east of Toronto.

Size of Site:
485 hectares (1,200 acres).

Staff:
When complete, Darlington will employ a staff of 850. Construction employment peaked at 6,800 in 1986.

Note: training for Darlington is carried out at the Eastern Nuclear Training Centre at Pickering (see page 3).

On Site:
Darlington Generating Station, four CANDU reactors, one vacuum building.

Tritium Removal Facility. Begun in 1984 and completed in 1988, the $124-million plant will extract tritium from heavy water used at Pickering, Bruce and Darlington to make the working environment safer for atomic radiation workers. About 2.5 kilograms (5.5 pounds) will be extracted each year and stored at the Darlington site. (See page 39 for more information on tritium).

Information Centre: 20,000 visitors tour the centre each year.

Soccer fields and future 49-hectare (121-acre) park.

Community Impact Payments:
A community impact agreement was signed by Ontario Hydro, the Town of Newcastle and the Region of Durham in 1977. Payments for impacts are agreed upon by all three parties. To date, about $1.5 million has gone to community services such as hospital expansion, fire protection services and economic development. The agreement ends one year after the final unit is in service.

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CANDU Design

CANDU Design

How A CANDU Reactor Works

A detailed explanation of atomic theory, fission and the principles of reactor design can be found in the section **Fission** (from page 65).

Essentially, fission is the splitting of the nucleus of an atom of Uranium-235 by a free neutron, a particle whizzing through the uranium until it hits and splits an atom. When an atom breaks into two or more fragments, free neutrons are also released.

In the CANDU reactor, the fissioning uranium is surrounded by a heavy water moderator. The moderator slows down the free neutrons to increase the likelihood that they will hit Uranium-235 atoms in the fuel and make them split. Newly-released free neutrons move so quickly that they shoot through the fuel atoms. To split atoms, the free neutrons have to be slowed to 2,220 metres (7,283 feet) per second.

Fission releases energy, as moving particles and as heat. The fissioning fuel heats heavy water which then heats ordinary water and turns it to steam. Jets of high-pressure steam turn the blades of the turbine generator to produce electricity.

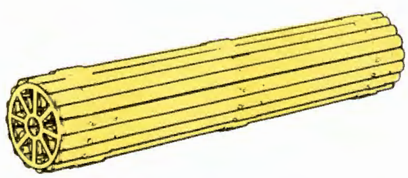
Major Components of The CANDU Design

Five major groups of components, each fitted inside the next, comprise the reactor core. The fuel fits into bundles inside the pressure tube, which fits inside the calandria tube. This assembly runs through the calandria, which is surrounded by the calandria shielding.

Fuel

Each natural uranium dioxide ceramic fuel pellet is about two centimetres (three quarters of an inch) long.

30 pellets are assembled in a Zircaloy-2 sheath, known as a pencil.



Pencils are assembled in bundles in such a way that they don't touch. A Pickering fuel bundle contains 28 pencils, a Bruce or Darlington bundle, 37 pencils. A bundle is about 49.5 cm (19.5 inches) long and weighs 22.5 kilograms (49.6 pounds).

Pressure Tube

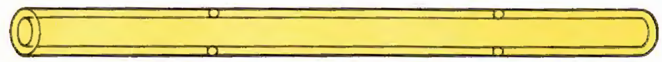
Fuel bundles are laid end to end in a 6.3-metre (20.6 foot) pressure tube made of zirconium-niobium. The pressure tubes extend through the face of the reactor and are capped with endfittings.

At Pickering, there are 12 bundles in each pressure tube. At Bruce and Darlington, there are 13, with half a bundle protruding from each end of the pressure tube into the endfitting. This is because the reactors use a different fuelling machine design.

There are 390 pressure tubes in each Pickering A reactor, 380 in Pickering B reactors, 480 in each Bruce and Darlington reactor.

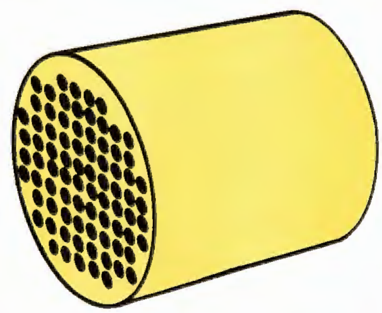
Pressure tubes are part of the heat transport system, discussed on page 10. Heavy water under pressure flows through each pressure tube and fuel bundle inside it. The heavy water carries the heat from the reactor core to the steam generators.

Fuel Channel Assembly



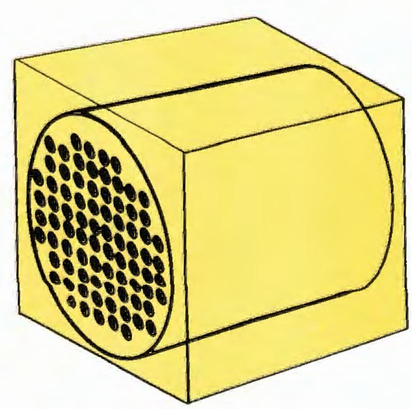
Each pressure tube fits inside a calandria tube made of Zircaloy-2. The two tubes are held apart by rings called garter springs. The space between the two tubes, called the annulus, is filled with carbon dioxide gas. The gas is circulated and monitored for the presence of moisture which would indicate a leak in either the pressure tube or the calandria tube.

Calandria



This large, stainless steel tank is filled with several hundred tonnes of heavy water moderator. Hundreds of fuel channels run through the calandria. Stainless steel end fittings support the pressure tube, provide links to the plumbing and contain removable plugs to allow for fuel changing, which is done by remotely-controlled fuel handling machines while the reactor is at full power.

Calandria Shielding



To provide shielding, the highly radioactive core is contained in a thick-walled concrete and/or steel structure. In stations built after Pickering A, this shielding structure, either a tank or vault, is filled with hundreds of tonnes of ordinary water.

Major Process Systems in The CANDU Reactor

Process systems are those systems which are necessary for the routine operation of a nuclear reactor. The most important systems are the moderator system, the heat transport system, the feedwater and steam generating system, the reactor regulating system and the fuel handling system.

Moderator System

Neutrons from the fissioning uranium fuel are moderated, or slowed down, by the heavy water in the calandria.

This heavy water moderator becomes irradiated and heated. As well, chemical compounds, referred to as poisons, can be added to it to regulate reactor power. To maintain the chemical quality of the moderator, it is continuously circulated through systems that purify it. Samples of heavy water can be taken at several points for analysis.

To keep the temperature at 65°C (149°F), the moderator water is pumped through heat exchangers which are cooled by lake water.

Heat Transport System

The CANDU heat transport system circulates pressurized heavy water through the fuel channels to remove the heat produced by fission in the nuclear fuel. It carries the heat to a set of steam generators. This also keeps the fuel from overheating. Note: other reactor systems in the world call this heat-removal system the heat transfer system or coolant system.

Feedwater and Steam Generating System

A large number of tubes carrying heavy water run through each of the four steam generators. The heat causes ordinary water in the steam generators, called feedwater, to boil. The pressurized steam flows via four separate steam mains to the turbine. After driving the turbine blades, it condenses and is pumped back to the boilers to be re-used.

Reactor Regulating System

The amount of heat the reactor produces is referred to as reactor power. Reactor power depends on the number of fissions taking place in the fuel. The number of fissions depends on the number of free neutrons in the core—the more free neutrons, the more fissions, and the higher the power.

To ensure reactor power is sufficient to produce the amount of steam required for the turbine generator, the number of free neutrons, the "neutron flux", as it is called, has to be measured and controlled. This is done by the reactor regulating system.

To help ensure reliability, the CANDU design uses two control computers, one continually and one on stand-by, either of which can independently run the control program using measurements which are duplicated or triplicated at each point.

If any measurements, such as neutron flux, coolant flow or temperature, are higher or lower than specified limits, the power is automatically adjusted in a particular zone or in the whole reactor. Four devices are used to control the number of free neutrons in the reactor: light water zone controls; mechanical control rods; adjuster rods; moderator poison.

Light Water Zone Controls

These are tubes running vertically through the core. The core of a CANDU is divided into 14 to 20 zones, with more zones in larger reactors. The power level in each zone is monitored and regulated by computer. If it is too high, ordinary water is added to the tubes to absorb neutrons. The more water in the tubes, the more neutrons absorbed, and the lower the power in that zone.

Mechanical Control Rods

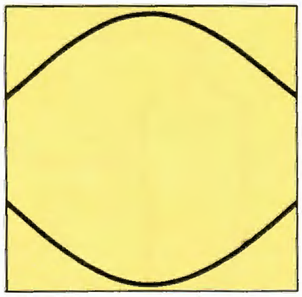
Four stainless steel-covered cadmium rods, held vertically over the core by a mechanical clutch, absorb neutrons and can be inserted or removed from the reactor at varying speeds. When slowly inserted, they assist the zone control absorbers in moderating reactor power. When dropped in, they lower power rapidly. The mechanical control absorbers are activated by computer but can also be manually controlled.

Adjuster rods

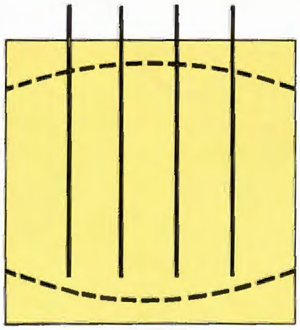
During normal operations, the vertically mounted adjuster rods are usually fully inserted in the reactor core to absorb excess neutrons and so ensure that neutron flux at the centre of the core, the hottest part, does not become too high when the reactor is at high power. This is called "flux shaping". The adjusters can also be driven out of the core to provide reactivity control.

In Pickering A and B and Bruce B units, the rods are made of cobalt and are irradiated to make Cobalt-60 (see page 39). Bruce A reactors do not have adjusters, they have enriched uranium boosters which are normally held outside the core but can be lowered into it to help regulate power.

Flux



Shaped Flux



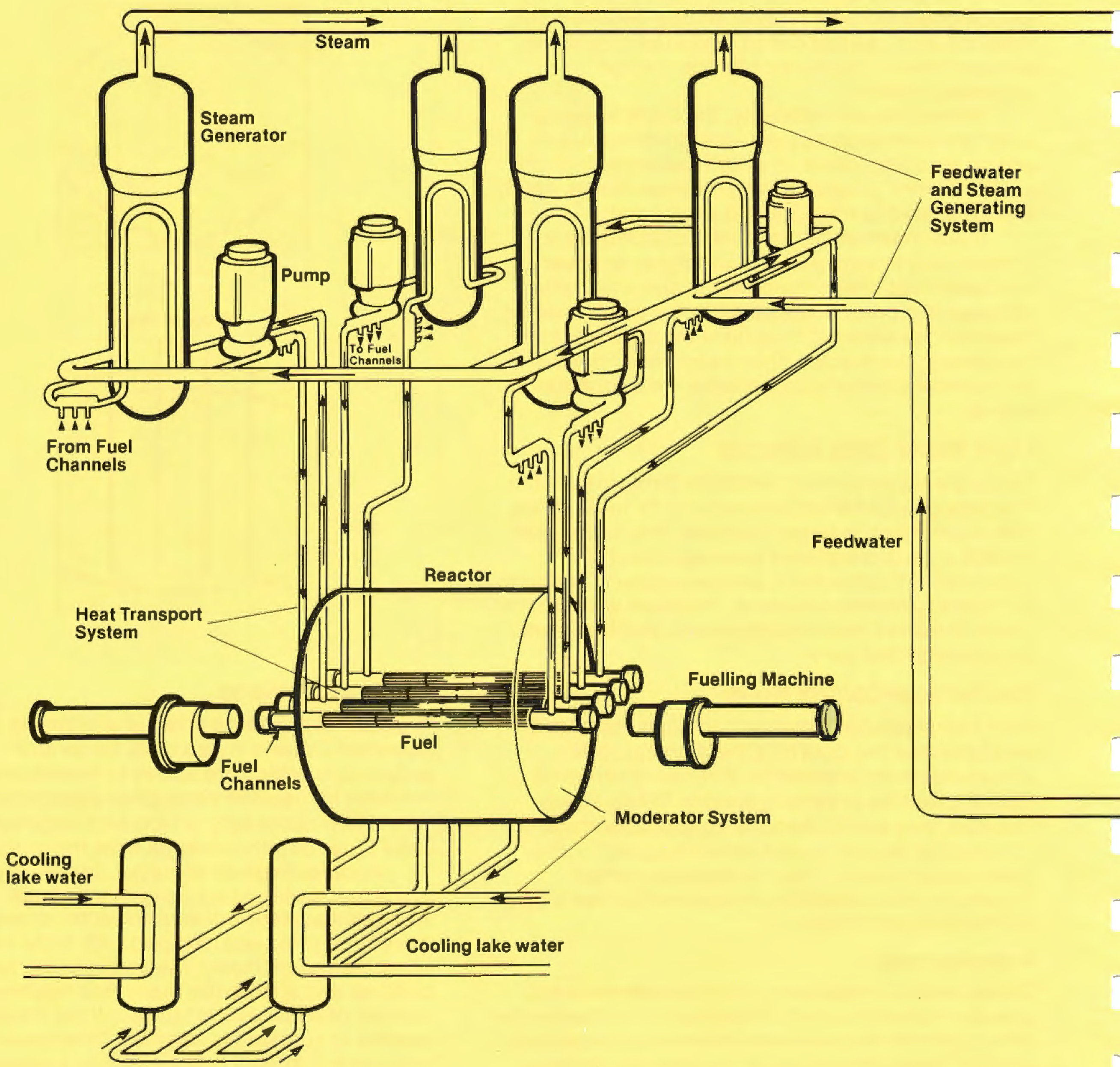
Moderator poison

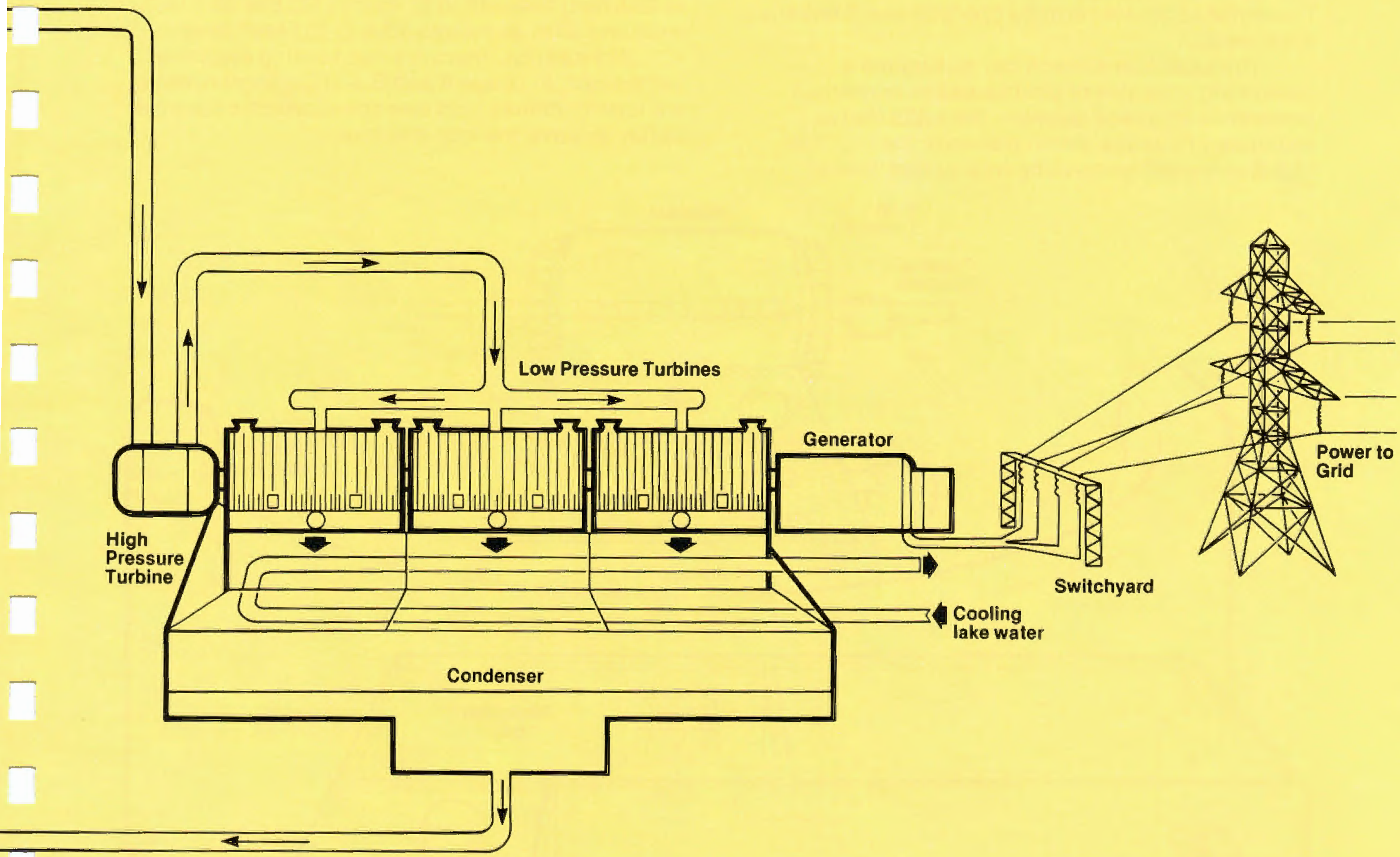
"Poison" is the name given to any strong neutron absorber. Ontario Hydro uses boron and gadolinium, which are added to the moderator to increase its neutron absorption capability.

When necessary, an ion exchange system is used to remove the poisons from the moderator.

Another neutron absorber, xenon, is produced in the fuel during operations. Sometimes, a shutdown system will shut a reactor down when there is no real need (see page 15). If the reactor is not restarted promptly, the xenon in the fuel will build up and absorb too many free neutrons and the number of fissions will fall below the threshold needed to sustain the reaction. This type of shutdown is known colloquially as a poison outage. Once it occurs, the reactor cannot be restarted for 36 hours. It takes that long for enough of the short-lived, neutron-absorbing poisons to decay so that a chain reaction can again be sustained.

The CANDU Reactor System




Low Pressure Turbines
Generator
Power to Grid
High Pressure Turbine
Switchyard
Cooling lake water
Condenser

Major Process Systems in The CANDU Reactor

Fuel Handling System

The fuel handling system is designed to refuel an operating reactor by remote control and to transfer the used fuel from the reactor to the storage bay.

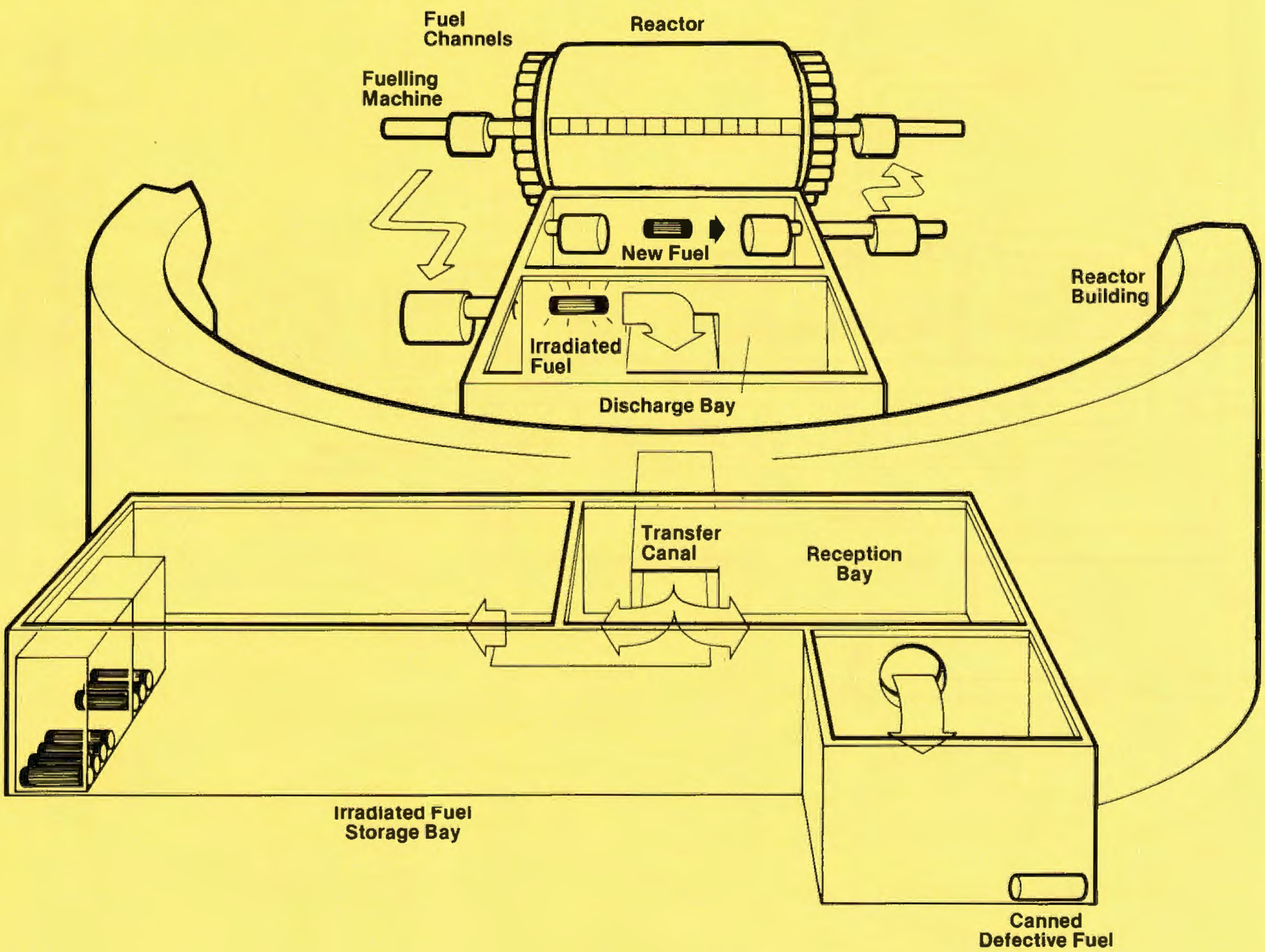
One fuelling machine inserts new fuel bundles into a fuel channel and irradiated fuel bundles are pushed out the other end into the second fuelling machine. From there they are transferred into the irradiated fuel storage bay. The operation is computer-controlled but the operator can intervene if necessary.

The used fuel storage bay resembles a swimming pool. It is of double-walled reinforced concrete with space between the walls that is monitored for leaks. When placed in the bay, fuel bundles are still generating heat called "decay heat", since it is produced by the decay of the radioactive fission products in the fuel.

Water flows over the fuel to cool it, then through a heat exchanger and then back over the fuel in a continuous circuit. The heat exchangers form a separate piping system containing lake water which is returned to the lake.

The main fuel bays at Hydro's operating stations range in size from six to nine metres (19.7 to 29.5 feet) deep, 10 to 17 metres (32.8 to 55.7 feet) wide and 20 to 46 metres (65.6 to 151 feet) long.

At Pickering, there are two fuelling machines per reactor. At Bruce A and B and Darlington, there are four machines (and one spare) which slide on a trolley to serve the four reactors.



Safety Systems in The CANDU Reactor

In the CANDU design, the safety systems are independent of the process systems and independent of each other. They do not function during normal operation of the reactor. They activate only if the process systems are unable to ensure the safe shut down or cooling of the unit. Canada's reactor design is one of the few in the world to have two independent fast shutdown systems. They are physically separate and have their own power supplies and monitoring equipment. They are failsafe: if any part fails, the reactor shuts down.

CANDUs are also equipped with backup sources of electricity, water and air.

Shutdown System No. 1

This is the primary means of quickly shutting down the reactor. Neutron-absorbing rods suspended above the reactor fall automatically into the moderator, shutting the reactor down in less than two seconds.

This shutdown system uses an independent logic system which records a number of reactor system measurements, such as neutron power, heat transport system pressure—by three separate means. If any two detect a process measurement outside the normal limit, the clutches holding the shutdown rods above the unit release automatically, the rods fall into the moderator and the unit shuts down, or "trips". If the electrical supply to Shutdown System No. 1 is lost, the shutdown rods will automatically fall into the reactor.

Because of the sensitivity of the shutdown instrumentation, reactors sometimes trip when there is no actual need. This is called a spurious trip.

Shutdown System No. 2

Shutdown System No. 2 rapidly injects poison—concentrated gadolinium nitrate solution—through nozzles into the moderator. This system is present in all CANDUs built after Pickering A.

Shutdown System No. 2 operates on a logic system with three separate means of measuring conditions similar to, but separate from, those measured by Shutdown System No. 1. The instrumentation for Shutdown System No. 2 is physically and electrically separate.

When Shutdown System No. 2 senses the need to trip the reactor, valves open between tanks containing compressed helium and those containing gadolinium. Helium drives the gadolinium from the tanks through nozzles into the moderator, shutting the reactor down within two seconds.

Emergency Core Coolant Injection System

A large break in the heavy water heat transport system resulting in a loss of coolant to the core is the most severe accident postulated in a CANDU. The emergency coolant injection system ensures that if there were a leak in the heat transport system, water would continue to circulate over the fuel and stop it from overheating.

If significant amounts of heavy water leaked from the heat transport system, the pressure in the system would fall. This would cause valves to open on the emergency core coolant injection tanks, forcing pressurized ordinary water into the core.

Any spilled coolant would collect in the reactor building sump. As the water injection tanks emptied, the operator would pump water from the sump through heat exchangers which would cool it before returning it to the heat transport system. The emergency cooling cycle would continue using a combination of heavy water and ordinary water.

Containment

Ontario Hydro's CANDU reactors use a negative pressure containment system, or vacuum building. At Pickering, one vacuum building serves all eight reactors. Bruce A and B stations and Darlington each have a vacuum building serving four reactors.

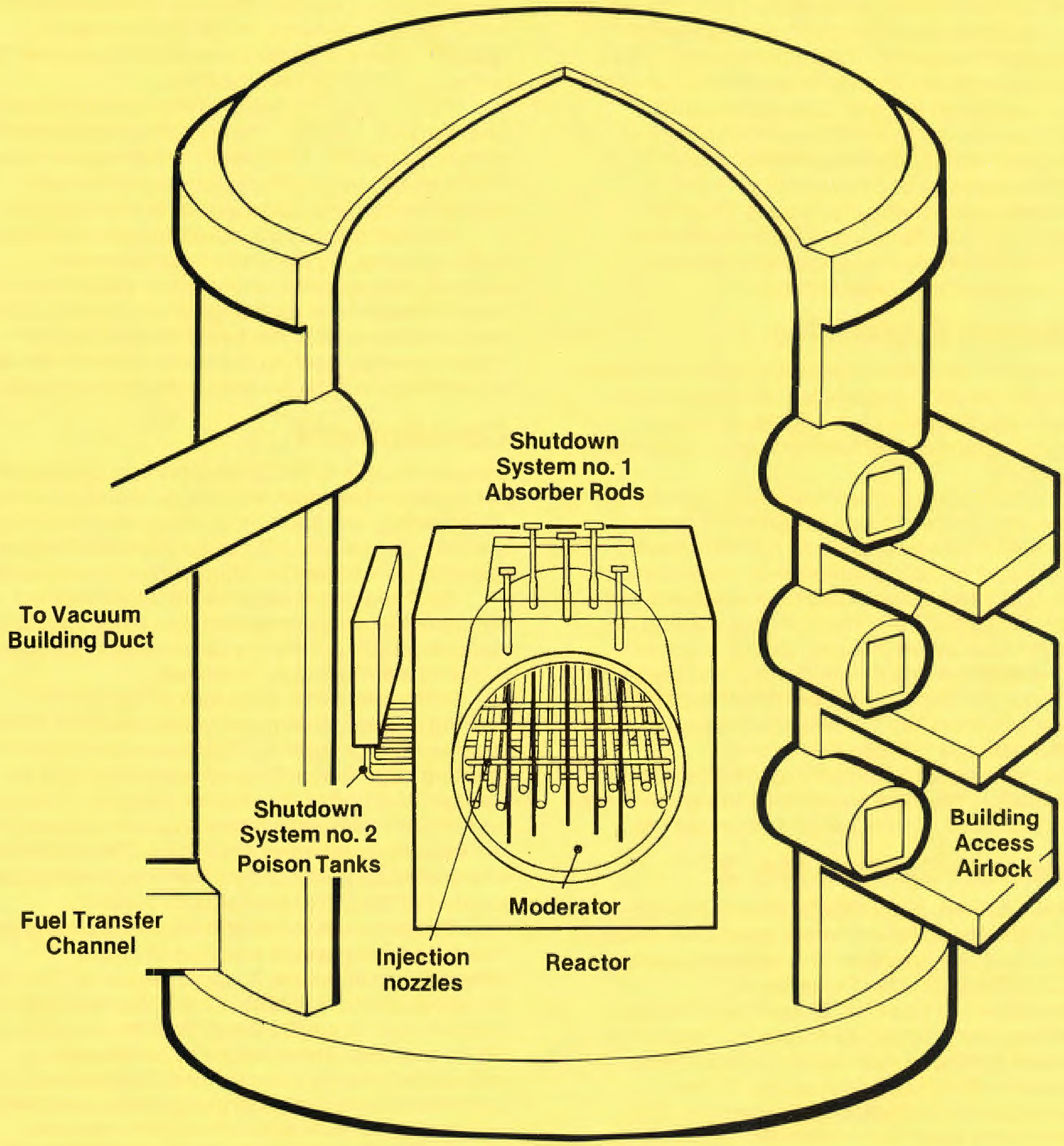
Each reactor is enclosed in a thick-walled concrete building connected by a large duct to the vacuum building. This is a large silo-like structure which is maintained as a vacuum.

In the event of a large leak in the reactor cooling system, steam and water would be released into the reactor building. The pressure would rise, opening large fast-acting valves connecting the vacuum building to the reactor building. The steam and any radioactive material would be sucked into the vacuum building where it would be condensed and cooled by water sprays from the dousing tank located at the top of the vacuum building.

The pressure inside the vacuum building and reactor building would stabilize at below atmospheric pressure. It would remain at that level for about 24 hours, which means that any leaks in containment would be leaks from the outside in. So for that time, there would be no releases of radioactivity to the atmosphere. The time would be used to institute any emergency measures deemed necessary, such as evacuation from the area.

During that 24 hours, short-lived radionuclides would decay, many radioactive particles would attach, or "plate", onto the vacuum building walls, and the accident would stabilize. After 24 hours, a slight vacuum would be maintained by gradually pumping the contents of the vacuum building through high-efficiency filters and charcoal absorbers to remove the most harmful radioactive materials. This filtered air would be vented outside the vacuum building through controlled releases.

Safety Systems in The CANDU Reactor



Additional CANDU Safety Features

To safely manage a reactor during an accident, three rules must be obeyed:

SHUT IT DOWN — COOL IT DOWN — CONTAIN IT

The ability to respond to these rules underlies the whole CANDU reactor design, not just that of its safety systems. In addition to the four safety systems—two shutdown systems, the emergency core coolant injection system and the containment system—several systems and components which make the reactor work also help ensure its safety in emergency conditions. This design approach is referred to as "defense in depth".

In an accident, the role of the emergency core coolant injection system in preventing fuel melting would be supported by the heat transport system and moderator system. As well as the containment system, there are four other barriers to contain any radioactivity on the station site, the others being the fuel pellet, the fuel pencil, the heat transport system and the exclusion zone around the station site.

Heat Transport System

While shutting down a reactor will stop new fissions from occurring, the fuel will still produce heat. In the CANDU, the heavy water in the heat transport system continues to circulate through the fuel channels, cooling the fuel.

Moderator as Heat Sink

If there were an accident in which there was a loss of coolant and a coincident failure of the emergency cooling system, the fuel would start to heat up. The pressure tubes would also heat up and, swelling or sagging, they would come into contact with the calandria tubes.

Surrounding the calandria tubes is the moderator—several hundred tonnes of heavy water at 65°C (149°F) and atmospheric pressure. The heat from the fuel would be transferred via the pressure tube and calandria tube to the moderator. Even though individual bundles would suffer some melting and be severely damaged, they would still be contained in separate fuel channels and so the moderator and heat transport fluid could still circulate around them, preventing the fuel from completely melting.

Moderator Dump

Pickering A reactors do not have a second high-speed independent shutdown system but do have provision for moderator dump. They can be shut down by draining (dumping) the moderator from the calandria: fissions will stop if there is nothing to slow down free neutrons. While this would be effective as a shutdown method of last resort in an emergency, the cooling effect of the moderator on the fuel would be lost.

Barriers to Radioactive Releases

There are five barriers to the release of radioactive materials from a CANDU reactor.

More than 99 per cent of the radioactive materials in the reactor are locked in the uranium dioxide fuel pellet itself. The uranium is in ceramic form which can withstand very high temperatures without melting or releasing radioactive material.

Even if fuel pellets were to melt, they would have to melt through the walls of the fuel pencil—the sealed Zircaloy-2 metal tube surrounding them.

Any radioactive material escaping the fuel would encounter the heat transport system, or piping, which contains the fuel. This is the third barrier. Filled with heavy water, the heat transport system is operated at a pressure far below its design limit.

The next barrier is the containment system—the reactor building and vacuum building, with 1.2-metre (four-foot) thick walls, described above.

Distance is the final barrier. There is a one-kilometre (half-a-mile) exclusion zone around a nuclear plant. Radioactive materials tend to attach themselves to the nearest surface and do not travel long distances. The exceptions would be vapors and gases, such as radioiodines and noble gases, which are carried with the wind. Most of them have fairly short half-lives and would be highly diluted in the atmosphere before they reached the exclusion boundary. See page 60, for the biological hazard and page 95 for emergency planning measures.

Regulation & Licensing

Regulation & Licensing

Atomic Energy Control Board

The Atomic Energy Control Act, 1946, required the creation of an Atomic Energy Control Board (AECB) to ensure strict federal control over the development and use of radioactive and related material and equipment for reasons of national and international health and security. Ontario Hydro's nuclear operations are regulated by the AECB.

The board of directors of the AECB is composed of five members, four of whom are appointed directly by order-in-council. The fifth is automatically the President of the National Research Council, which is itself an order-in-council appointment. The only full-time position on the board is that of the President and CEO. There is a 250-person scientific, technical and administrative staff. The AECB reports to Parliament through the Minister of Energy, Mines and Resources.

The Directorate of Reactor Regulation has jurisdiction over safety evaluation, licensing and inspection of all nuclear power plants, research reactors and particle accelerators in Canada. AECB staff are stationed at all Ontario Hydro reactor sites (five at Pickering; three at Bruce A; two at Bruce B; four at Darlington).

The Directorate of Fuel Cycle and Materials Regulation is responsible for the many non-reactor aspects of nuclear energy use in Canada. It also ensures that exports of equipment and supplies do not violate the obligations of the Nuclear Non-Proliferation Treaty (1968). Ontario Hydro's primary contacts with this directorate are in the areas of safety and licensing for radioactive waste management facilities, heavy water plants and transportation of radioactive materials.

The Regulatory Research Branch reviews the latest international research in the areas of environmental physics and health effects of radioactive materials. Regulatory safety standards may be modified in light of new data.

Regulatory Approach

The following, reprinted from "Nuclear Safety Management: Goals and Objectives", part of Ontario Hydro's submission to the Ontario Nuclear Safety Review describes the Canadian approach to nuclear regulation:

> The underlying principle which has governed the Atomic Energy Control Board's approach to regulation of nuclear energy development in Canada is that primary responsibility for achieving high standards of nuclear safety in design, construction, commissioning, operation and decommissioning of nuclear plants rests with the licensee. The AECB does this by setting what they consider to be technically and publicly acceptable standards with respect to public risk, and then requiring the owner/operator to define exactly how this standard will be met. The role of the board is one of ensuring that the licensee lives up to its responsibility. The role of the AECB staff is to audit the operating company's performance on behalf of the board. The role of Ontario Hydro is to ensure that well-established safety policies and principles are in place and being followed, that the design and operation of nuclear stations is carried out under clear assignment of responsibility and authority in accordance with written procedures, and that work planning and control is properly reviewed and approved.
>
> This principle of operating company responsibility is generally supported internationally but the extent to which it is implemented differs widely. Canada and Great Britain, for example, put much more emphasis on this factor than do countries where there tend to be highly detailed rules imposed by the regulatory bodies. The safety culture within the operating company is related directly to that measure of responsibility. In Canada, the owners are responsible for proposing, justifying and defending their safety assessments, including the necessary research and development programs to support these assessments. In such an environment, there is considerably more emphasis on understanding the details of, or the consequences arising from, accidents at nuclear plants than in environments where detailed rules exist and R&D is primarily the responsibility of the regulator.

Major Licensing Steps For A Nuclear Reactor

The major steps leading up to issuance of Site Acceptance are:
- submission of a letter of intent
- public announcement by AECB
- coordination meetings between AECB and appropriate federal and provincial departments. (It has been a long-standing AECB policy to require adherence to provincial legislation and requirements of general applicability)
- submission of site evaluation report
- public meeting or public hearing by provincial or federal government agencies
- AECB staff review and recommendation goes to Board (the AECB limits its consideration at this stage to the question of whether a plant of the general design proposed could be built and operated at the particular site to meet established AECB requirements)
- Board determination
- public issuance of Site Acceptance

The major steps leading to a Construction Approval are:
- letter of application (from utility)
- public announcement by AECB
- submission of (preliminary) Safety Report
- submission of Quality Assurance program
- submission of staffing and training plans
- review and evaluation by AECB staff (including numerous meetings and correspondence with applicant)
- AECB staff report and recommendation to Board
- Board determination
- public issuance of Construction Approval

The major steps leading to an Operating Licence are:
- letter of application
- public announcement by AECB
- submission of Final Safety Report, including description of plant design as built and completion of safety analyses
- submission of Commissioning Programs
- submission of Operating Policies and Principles
- submission of policy, plans and procedures for Radiation Protection
- development of on-site Emergency Plans and completion of plans and arrangements with local public authorities for off-site contingencies
- AECB staff approval of arrangements for safeguards and physical security
- submission of formal assurances regarding completion of construction and commissioning
- AECB examination and authorization of key operating personnel
- application to acquire heavy water and fuel
- AECB approval
- application to load heavy water and fuel
- AECB approval
- AECB staff reviews, reports and recommendation to Board (AECB staff would have been on site for at least the latter part of construction and the complete commissioning program)
- Board determination
- public issuance of Provisional Operating Licence (for start up and post-criticality testing)
- further AECB staff reports and recommendations
- Board determination
- public issuance of Operating Licence (for limited period, typically 1 to 5 years)

From F.C. Boyd, "Licensing and Safety of Nuclear Power Plants in Canada", (Ottawa: AECB, Sept. 1981). Reprinted with permission.

Licensing A Nuclear Reactor

Before a utility approaches the AECB, it must have the provincial government's approval for the project. The socio-economic and environmental impacts of a nuclear plant are provincial matters. The AECB's jurisdiction is over the safety of design and operations of the facility. AECB licensing requirements for a nuclear reactor are stringent and detailed. There are three steps of approval.

Site Acceptance is granted when the AECB is satisfied that the proposed site is appropriate for the specific nuclear facility.

Construction Approval enables the utility to build the reactor, to the design specifications agreed upon with the board. At this point, on-site AECB inspectors are assigned to the project to oversee compliance with the design. They will continue to work at the reactor when it is operating to ensure safety standards are being met.

Ontario Hydro uses exhaustive quality assurance standards in nuclear construction. All parts in a reactor are traceable to the supplier. For example, the part of the ingot from which each pressure tube was made is known, as well as the location of that tube in the reactor. Suppliers and distributors are documented along with the material they supplied. Record is kept of every weld, name of the welder, the technique used, the radiograph of the weld. This approach has been adopted by some American utilities to increase station reliability and has been incorporated into AECB regulations. Darlington was the first station for which the quality assurance program standards were submitted with the application for construction approval.

An *Operating License* is required before Hydro can start up a new reactor. In the application, Hydro must submit its detailed operating manuals, policies and procedures manuals and thousands of pages of computer analysis showing the consequences of virtually every type and combination of malfunction. The AECB can require the applicant to do more analyses or modify the design before or after a license is granted. The license for a commercial nuclear reactor must be renewed at least every five years, or more frequently at the AECB's discretion.

As a condition of the license, the utility must notify the AECB promptly of any occurrence or situation which could affect the safety of the plant. Notification includes filing a Significant Event Report (see page 33).

Full-time AECB project officers are assigned to each of Ontario Hydro's nuclear sites (five at Pickering; three at Bruce A; two at Bruce B; four at Darlington). As licensing officers, they review licensing submissions, coordinate reviews with other AECB divisions and make recommendations to the board on proposed licensing activities. As on-site inspectors, they monitor compliance with licensing requirements and carry out routine inspections. They verify the radiological data and operating records maintained by the utility. AECB on-site inspectors and headquarters officials have the authority to order any reactor to reduce power or shut down until licensing conditions are met.

Unit first operators, shift operating supervisors and shift supervisors must be authorized by the AECB. As part of the authorization process, shift supervisors and unit first operators must pass five exams set for each position by the AECB. Station manager and production manager appointments must also be approved by the AECB. For further details on operator training, see **Nuclear Operators,** page 29.

Transportation of Radioactive Materials

Ontario Hydro uses six types of containers to transport radioactive materials, depending on the radioactivity level of the contents. All are built to the standards detailed in the September 29, 1983, amendments to the Transport Packaging of Radioactive Materials Regulations, Atomic Energy Control Act.

Strong Industrial Container

Used to transport low-level waste. While it is manufactured and tested according to AECB transport regulations, the strong industrial container does not require an AECB license.

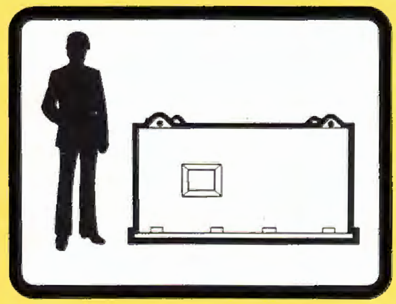
Type A Container

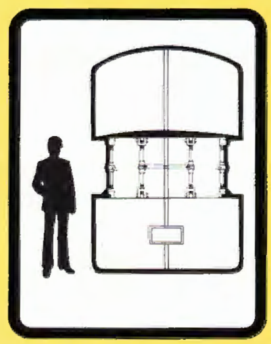
This container is used for the transportation of low-level waste. Before the AECB grants a transportation license, it must be satisfied that the results of Ontario Hydro's scale model testing and/or computer modeling and analysis demonstrate that the container will be able to withstand a rainfall of 50 millimetres (2 inches) an hour; a 1.2-metre (four-foot) fall onto an unyielding surface; an attempted puncture by a steel bar. If the package will be used to transport gas or liquid waste, it must be able to withstand a more forceful puncture attempt as well as a nine-metre (30-foot) fall.

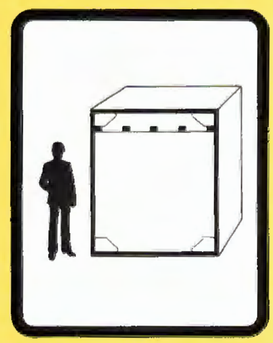
Type B Container

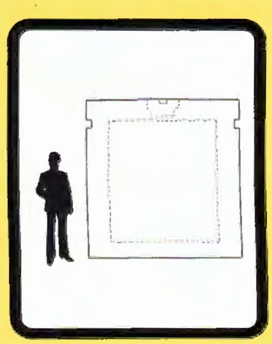
A number of containers built to Type B standards are used at Ontario Hydro. Some examples would be the two-bundle cask, used for transporting irradiated fuel; the bulk resin flask, which holds resins and higher level waste; the tritiated heavy water transportation package.

All type B containers must be able to withstand a nine-metre (30-foot) drop onto an unyielding surface; a one-metre (3-foot) drop onto a steel spike; 30 minutes in an 800° C (1472° F) fire; eight hours immersed in 15 metres (50 feet) of water. Only after field testing and/or computer analysis has demonstrated the containers can survive these punishments will an AECB license be granted.









Nuclear Safety

Nuclear Safety

Nuclear Safety

Radiation Exposure and Emission Standards

The Atomic Energy Control Board (AECB) accepts and enforces the standards for radiation exposure set by the International Commission on Radiological Protection (ICRP). Founded in 1928, the ICRP is an independent, non-government, expert body whose members are chosen on the basis of individual merit in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry, biophysics. Through review of the latest research, the ICRP establishes basic principles on which radiation protection measures should be based.

In order to get and keep nuclear station operating licenses, Ontario Hydro must demonstrate continually to the AECB that each reactor is designed and operated in such a way as to ensure that public and worker exposure limits under routine and accident conditions will not exceed ICRP standards.

Standards For Routine Situations

During normal operations, small but measurable quantities of radioactive material are emitted from reactors to the atmosphere, when air is vented from the reactor building, and to the lake, because of the water drawn from it to cool the reactor.

The public's radiation exposure is calculated by measuring these emissions. The ICRP states that public exposure to routine radiation emissions from nuclear power plants should not exceed 500 millirems a year. The AECB authorizes emission limits on each category of radionuclide emitted and these are known as Derived Emission Limits (DEL). Ontario Hydro's target is to control emissions at less than one per cent of the limit for each category of radionuclide. Actual exposures to people living in the neighborhood of the plant are much lower.

Standards For Accident Situations

The AECB requires Ontario Hydro to demonstrate that the consequences of the worst-case nuclear station accident would not result in radiation exposures higher than the AECB release limits shown in the chart below. Safety analyses are submitted to the AECB regularly throughout the operating life of the station, as well as during its construction. At any time, the AECB can suspend or revoke a station's operating license if it believes the station would not be able to stay within release limits during an accident. Safety analyses are discussed more fully under **Learning from Operating Experience**, page 33.

Maximum Permissible Radiation Exposure Limits for Accident Situations

	Single Failure(1)	Dual Failure(1)
Maximum Frequency(2)	1/3 yr.	1/3 000 yr.
Maximum Individual(3)		
Whole body	0.5 rem	25 rem
Thyroid	3.0 rem	250 rem
Collective Population		
Whole body	10 000 rem	10 000 rem
Thyroid	1 000 000 rem	1 000 000 rem

(1) A single failure would be the loss of a process system; a dual failure, that loss coupled with the failure of the appropriate safety system. One of the worst conceivable dual failure accidents in a CANDU would be a large break in the heat transport system combined with the failure of the emergency core coolant injection system.

(2) Maximum frequency is the postulated maximum number of times this sort of accident could occur in a certain number of reactor years of operation.

(3) Maximum individual is assumed to be a member of the most radiologically-sensitive age group, who is assumed to remain at the site boundary throughout the periods of radioactive release.

How Radiation Gets Out Of A Nuclear Station

During the more than 25 years (156 reactor years) of Ontario Hydro's nuclear operations, there has never been a known injury to the public involving radioactivity. In fact, there has never been a release of radioactivity from any Ontario Hydro nuclear generating station that resulted in a measurable radiation exposure to any member of the public.

As the diagram of the CANDU on page 12 illustrates, lake water is piped through the reactor to cool a number of systems, chief among them: the heavy water in the moderator heat exchangers and in the shutdown heat exchangers for the heat transport system. On the non-nuclear side of the plant, lake water is used to condense the high-pressure steam once it has passed through the turbines.

Lake water flows through the reactor in pipes and does not come into direct contact with any radioactive substances. It is the cool temperature of the lake water which is needed, not the water itself. In heat exchangers, the lower temperature of the lake water cools heavy water, flowing through separate pipes, which becomes heated and irradiated as it circulates through the reactor core.

Small leaks of heavy water into the lake water can occur at joints in the piping system. When heavy water is irradiated, tritium, a radioactive isotope of hydrogen, forms in it and builds up over time. Most radioactive emissions to the lake are of tritium. The lower the concentration of tritium in the heavy water, the less can get into the lake. Environmental protection is one reason Hydro will be removing tritium from heavy water.

Such a tremendous volume of water passes through a CANDU reactor—one and a half million litres (110,000 gallons) each minute—that any leaks of tritiated heavy water into the lake water circuits are greatly diluted before they reach the lake.

The tritium level in Lake Ontario water is significantly lower today than it was in 1963, the peak year of contamination from above-ground nuclear weapons tests, when there were 2,000-3,000 picocuries of tritium per litre of Lake Ontario water. In 1987, there were 350-400 picocuries of tritium per litre of Lake Ontario water.

Very low levels of radioactivity are also released to the atmosphere from the reactor ventilation system. Before being released, any radioactive dust and vapor is first passed through high-efficiency particulate filters and charcoal filters, which trap most radioiodines. After filtration, air is monitored then exhausted through a stack. Radioactive emissions into the air consist mostly of small quantities of tritium and radioactive noble gases. Noble gases, which are chemically inert, do not combine with body tissue, and are only a minor external hazard. There may also be some fine particles of radioactive dust emitted.

Heavy Water Plant Emissions

The heavy water used in the moderator and heat transport systems of Hydro's reactors is produced at the Bruce Nuclear Power Development, near Kincardine. Hydrogen sulphide, a very toxic gas, is used in heavy water production (page 68). Most of the gas is recycled through the plant system. A small amount, however, enters the flare system, is directed to the flare tower where it is burnt off, releasing sulphur dioxide, a more buoyant and less toxic gas, into the atmosphere.

Plant emissions are subject to strict regulation by the Ministry of the Environment. No member of the public has ever been injured through a hydrogen sulphide release.

Maximum Permissible Radiation Exposure Limits For Atomic Radiation Workers

Body Organ	Quarterly Limit	Annual Limit
Whole Body (including blood-forming and reproductive organs)	3 rem	5 rem
Skin, thyroid gland, bone	15 rem	30 rem
Extremities (forearm, hands, ankles, feet)	38 rem	75 rem
Other single organs (e.g. lens of eye, lung, etc.)	8 rem	15 rem

Heavy Water Plant Safety

Ontario Hydro's Heavy Water Plant, located at the Bruce Nuclear Power Development, is licensed by the Atomic Energy Control Board and emissions are subject to strict Ontario Ministry of the Environment regulations.

Because the hydrogen sulphide used to distill heavy water from lake water (see page 68) is a very toxic gas, safety is a top priority at the heavy water plant. Employees use a buddy system. Heavy water plant employees have worked almost five million manhours with no fatalities or loss-of-time injuries.

No member of the public has ever been injured through a hydrogen sulphide release. A comprehensive emergency plan covering employee rescue techniques, communications and off-site survey techniques is in place at the Bruce Nuclear Power Development and is exercised each month.

Public Safety

Radioactive Emission Limits

During the normal operations of a CANDU reactor, there are small releases of radioactivity into the air and water. The Atomic Energy Control Board standards say that environmental emissions must not exceed a level which could give any member of the public an exposure in excess of 500 millirem a year.

To ensure that exposures are kept below the AECB limit, Ontario Hydro and agencies of the provincial and federal governments continuously monitor air, precipitation, milk, drinking water, vegetation, algae and fish—all the possible paths for radiation to enter the environment and the food chain.

In this way, each category of emission is monitored—tritium, noble gases, Iodine-131 and particulates in the air and tritium and other beta radiations, along with gamma radiation, in the water.

Ontario Hydro aims to keep emissions in each category (called Derived Emission Limits) to less than one per cent of the annual AECB emission limits so that a theoretical person, receiving the maximum exposure possible from all Derived Emission Limits, would not receive an exposure in excess of the AECB public exposure limit. The actual exposure of people living in the neighborhood of the plant is much lower.

Maximum Permissible Radiation Exposure Limits For Public

Body Organ	Annual Limit
Whole Body (including blood-forming and reproductive organs)	0.5 rem
Skin, thyroid gland, bone	3 rem (except for the thyroid of a child under 16, where limit is 1.5 rem)
Extremities (forearm, hands, ankles, feet)	7.5 rem
Other single organs (e.g. lens of eye, lung, etc.)	1.5 rem

Worker Safety

Safety Record

From 1955 to 1987, in more than 133 million worker-hours of research and commercial operation, there were no fatalities among nuclear operations employees at work for any reason. No employee has ever been injured due to radiation and there has never been a medically-significant radiation exposure.

Despite the fact that an increasingly large percentage of Ontario's electricity is being supplied by nuclear power (47.5 per cent in 1987), the annual amount of radiation each atomic radiation worker is exposed to has declined sharply since the commercial nuclear program began at Douglas Point in 1968. Then, the average annual exposure was 1.4 rem per exposed worker. In 1987, it was 0.39 rem. This decline can be attributed to better work practices and improved plant design.

Mortality Study Results

A 15-year mortality study (1970-1985) of deaths from all causes among male Ontario Hydro employees and pensioners shows fewer nuclear station employees have died than would be statistically expected. Based on general male mortality rates in Ontario, 130 deaths would have been expected in the 15-year period, 25 of them from cancer. There were 17 cancer deaths among the 76 actual deaths. This doesn't prove men are healthier by working in nuclear stations, but simply shows that no adverse health effects have been detected amongst those working there.

Female Atomic Radiation Workers

On May 1, 1985, the Atomic Energy Control Board concluded that women who are not pregnant will be allowed to work within the same radiation protection limits as men. Until then, the AECB required lower radiation exposure levels for women. This restriction kept skilled tradeswomen from working in Hydro's nuclear program. It also meant that management and professional women could not obtain the necessary field experience for their advancement in nuclear operations.

Controlling Radiation Exposure

All atomic radiation workers must take a series of radiation protection courses and pass exams in order to qualify to work in a nuclear plant. They must requalify at least every two years.

Strict contamination control procedures are in place. The plant is divided into three zones, with zone three containing the high-level radioactivity. To avoid spreading radioactive dust, hand and foot contamination monitors must be used when moving from one zone to another. Contamination meters are used frequently to measure levels on individuals and in radioactive work areas. To measure personal exposure, all workers wear dosimeter badges on their chests and, when working on radioactive equipment, wear extremity dosimeters on their finger tips. Respirators and protective clothing are used when needed.

Atomic radiation workers' urine is monitored weekly for contamination by tritium, a radioactive isotope of hydrogen which is produced in the heavy water in CANDU reactors during their normal operation (see page 39). Once a year, all zone two and three employees who may be exposed to radiation are scanned by a whole-body monitor for internal gamma radiation. Workers use thyroid monitors themselves when they feel it is necessary. More extensive and frequent monitoring techniques are used when the exposure hazard is judged to be greater than usual.

If employees receive exposures bringing them close to the quarterly limit, they are transferred to less hazardous duties until the next quarter begins.

The keys to controlling exposure are knowledge and planning. Before work begins in an area, it is surveyed for radioactivity. The kinds of radioactivity are determined and appropriate clothing, respirators and shielding are used. When possible, waiting several hours or days before entering a high-activity area can lower the radiation levels, as short-lived nuclides decay. In some instances, surfaces can be decontaminated before work begins.

In very hazardous environments, detailed work plans are made. The length of time an individual worker is in the environment is closely controlled. Some procedures, such as removing the pressure tubes from Pickering units 1 and 2, are rehearsed using the appropriate equipment and clothing at a mockup, so that once in the reactor vault, the work goes like a well-choreographed dance.

If any atomic radiation worker is not satisfied that the task assigned has been made as safe as possible or feels that it involves a risk he/she does not want to take, the assignment can be refused. Hydro will modify the work plan or refer the question to the AECB for arbitration.

Commissioning

Commissioning

Commissioning

Commissioning is one of the most exciting stages of reactor operation. This process ensures that all equipment and systems will perform the way they are designed to when they are declared "in service".

It takes about eight years to commission a four-reactor Ontario Hydro nuclear station. Two to three years before the start-up of the first reactor, a commissioning team of operations staff is formed to oversee the transition of the project from design, through construction, to operation. As this transition period nears the in-service date, the number of staff on the team grows.

The commissioning process is split into four phases.

Phase A lasts at least four years. The commissioning team writes operating specifications and testing procedures for the 150 systems involved with a reactor. Each system must be tested as closely as possible to the conditions it was designed to tolerate without creating an emergency situation.

All operating systems are given functional tests to ensure that when a button is pushed, appropriate relays behave as they should. Safety systems get a wire-by-wire inspection to make sure they are properly connected.

The order in which each system is tested is crucial, because some cannot be tested until others are in place. Early in the program a detailed schedule is produced by the commissioning team. Meeting the milestones of this timetable while accommodating changing priorities and the correction of faults is one of the most challenging aspects of commissioning.

Before the reactor is started, the unit is taken to normal operating temperature in order to check systems under "hot" conditions.

Using design specifications and commissioning experience, the commissioning team develops training and operating manuals for all systems. Operators and supervisors are trained according to Atomic Energy Control Board (AECB) requirements.

When all systems have proven they can do their job, Phase B begins. The reactor is loaded with fuel and heavy water, and goes critical—it is started for the first time at low power (0.1 per cent). Phase B testing, which usually lasts about two weeks, confirms that the shutdown systems work properly, and that control systems respond correctly.

Phase C, the busiest period, covers the time between low power and 100 per cent power. The reactor is producing steam, the turbine generator is run for the first time, and electricity is supplied to Hydro's transmission network. More tests are done to determine the response of the reactor under various conditions and to demonstrate the effectiveness of back-up systems. Phase C usually takes three to four months for the first reactor at a station, and about a month for subsequent reactors.

During Phase D the reactor is run at full power for one to three months before it is declared reliable and available for commercial service. This is a probationary period, during which the reactor is run for a significant time in order to allow longer-term problems a chance to appear.

The AECB is involved in all phases of commissioning from the initial production of the detailed commissioning specifications to the final full-power tests. The board monitors key tests and must give approval before work can proceed to the next major milestone. Its approval is required before heavy water is added to the unit, before fuel is loaded, before the reactor goes critical, and at various stages up to 100 per cent power.

Nuclear Operators

Nuclear
Operators

Nuclear Operators

While the CANDU is designed to shut down safely without operator intervention, operating staff are highly trained. The skill of Ontario Hydro's operators was demonstrated in 1983, when a pressure tube failed in unit 2 at Pickering, causing a loss-of-coolant accident. The operators safely shut down the reactor before the situation became serious enough to trigger the automatic shutdown system.

Operator Training

The people running Ontario Hydro's nuclear reactors are trained and examined for up to eight years before they are fully qualified to do the job.

Field Operator Training

Operator trainees must have Grade 13, with math and science. They enter a two-year operator-in-training program which includes extensive radiation protection training and study of the systems used in running the station.

They then work for three or more years as field operators, monitoring equipment and systems and conducting operations in the plant as directed by the unit first operator.

First Operator Training—First Year

Some experienced field operators are chosen for the rigorous three-year first operator training program. The first year covers general technical training. At the end of the first six months, the first operator trainees write an Ontario Hydro exam on conventional electrical technology and scientific principles. That exam is followed by an AECB exam on the same material. After the second six months, the trainees' knowledge of nuclear subject matter is tested in the same way.

First Operator Training—Second Year

After the first year, the training becomes station-specific: people are trained to work at either Pickering A or B, Bruce A or B, or Darlington. To work at another station, a unit first operator must repeat the station-specific portion of the training program before being authorized to work.

The second year begins with six months' training on the station's conventional systems. After passing written Hydro and AECB exams, the trainees spend time in the plant where they are given a series of oral exams on the role and function of the equipment and station systems.

The second half of the second year follows the same Hydro-AECB written examination approach but deals with nuclear systems. The trainees spend two five-week periods learning how to operate the station on a control room simulator. An exact replica of the control panels of the reactor unit, the simulator is connected to a sophisticated computer which can replicate the signals received in the control room during normal and emergency conditions.

First Operator Training—Third Year

The first half of the third year is spent on an intensive radiation protection course given by Ontario Hydro, where trainees learn how to minimize radiation exposure to workers who will be in the plant. At this point, the trainee becomes a copilot operating the unit under the supervision of a unit first operator.

The trainee must then pass an oral examination given by the production manager. If Ontario Hydro is satisfied with the individual's competence, the utility requests AECB approval for the individual's nomination as unit first operator.

All first operators must retrain annually on the station simulator.

Shift Operating Supervisor Training

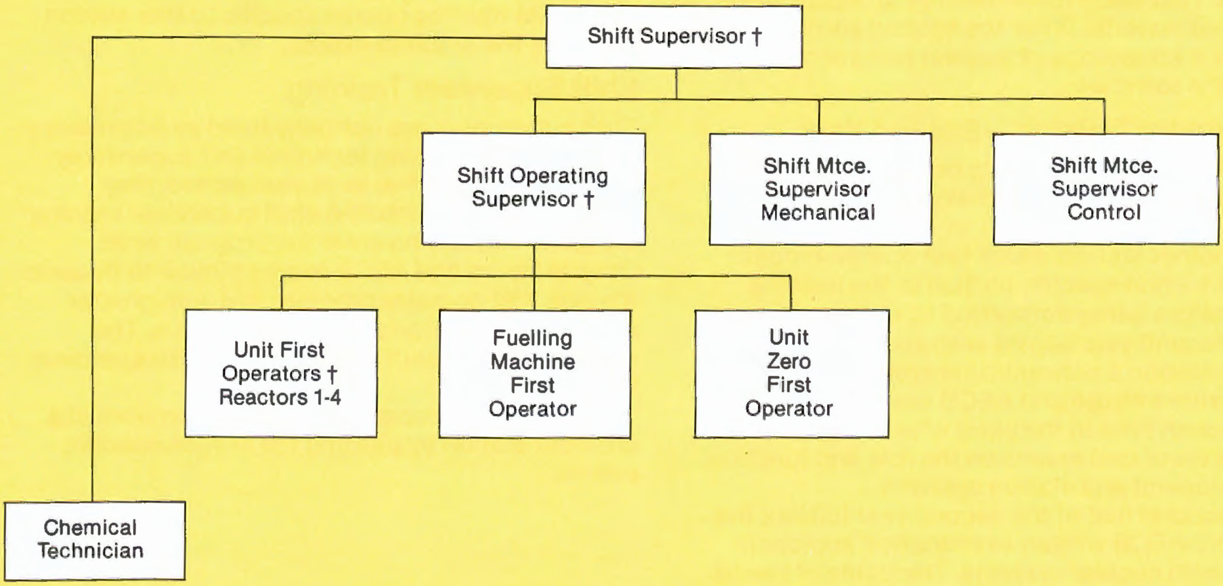
Shift operating supervisors are chosen from the first operator ranks for extra training and must also be authorized by the station manager and approved by the AECB. To be authorized to work at a different station, shift operating supervisors must take the part of the training course specific to that station and pass the required exams.

Shift Supervisor Training

Shift supervisors are normally hired as engineers-in-training. After gaining technical and supervisory experience over a five to 10-year period, they compete for entry into the shift supervisor training program. Those who enter the program write Ontario Hydro and AECB exams similar to those in the unit first operator program, but with greater emphasis on design and safety analysis. The authorization of shift supervisors is also approved by the AECB.

Shift supervisors must requalify to work at a different station by passing the station-specific exams.

Staff Organization For One Shift At An Ontario Hydro Nuclear Station*



*Shifts are 12 hours, from 8 to 8. There are about 100 people on each shift. Each station has five shift crews.
A station refers to a four-unit station. At Pickering and Bruce there is one control room for each set of four reactors.
†Staff in these positions are authorized by the station manager with the approval of the AECB after, completion of an appropriate Ontario Hydro program and AECB examinations.

Staff Organization For One Shift At An Ontario Hydro Nuclear Station

Shift supervisor

- supervises the crew of operations and maintenance staff that run the plant
- approves unit restarts and increases in reactor power
- if Ontario Hydro's System Control Centre requests that the station generate more or less electricity, the shift supervisor decides which unit must produce more or less power.

Shift operating supervisor

- supervises all operators on a crew.

Unit first operator

- is directly responsible for the safe operation of a reactor
- communicates with System Control about the reactor's output
- has authority to shut down the reactor at any time
- pushes the control panel buttons operating the reactor, or supervises a trainee doing it
- directs field operators working outside the control room (all electricity-production machinery is not automated—valves must be opened and closed, dials such as those on the turbine, must be read).

Each unit first operator supervises at least one second operator and generally two assistant operators.

Fuelling machine first operator

- supervises all operators of fuelling machines and may operate one himself.

There are generally five to eight fuelling machine operators per station crew.

Unit zero first operator

- operates or supervises operation of all services common to the station (these vary from station to station, but could include power, water and the screen house, which screens the entry of fish and debris in the water intake from the lake).

There are about 10 to 15 unit zero operators per station crew.

Shift maintenance supervisor—control

- supervises the senior control technician and his staff of control technicians who do maintenance, testing and calibration of instrumentation and control equipment.

Shift maintenance supervisor—mechanical

- supervises the foreman and his staff of mechanical maintainers who do maintenance and testing of mechanical equipment.

Chemical technician

- is responsible for taking chemical samples from various systems and conducting conventional and radiological analyses on them (for example, the pH of heavy water in the heat transport system has to be monitored; it will corrode the piping if it is too high or low).

Nuclear security guards

- are assigned to each shift.

Operating Experience

Operating Experience

Operating Experience

Learning From Operating Experience

Ontario Hydro's nuclear program emphasizes learning from experience to ensure safe, reliable operation.

Station management and staff must review their own operating experience, identify problems and implement solutions. The Technical Section, an organization of approximately 75 engineers and technicians at the plant, plays a major role in this process, as does the Quality Assurance Section.

Operating experience is analyzed in a number of ways. The station's performance is measured by such standards as public safety, worker safety, reliability, cost and environmental protection. The performance of key systems and equipment is monitored and analyzed. Any unusual operating event is documented in a Significant Event Report which is filed with the Atomic Energy Control Board (AECB). These reports undergo a formal review process and corrective actions are identified. Every Significant Event Report is reviewed by the station manager.

Operating experience is documented in a number of different reports including: Significant Event Reports, Quarterly Technical Reports, In-Service Reports and Commissioning Reports. These are made available to station staff, central nuclear operations staff, designers, researchers and others involved in contributing to safe plant operation.

A station's technical section is backed up by experts in a number of other parts of Hydro. Two departments, Central Nuclear Services and Radioactivity Management and Environmental Protection, are responsible for assessing operating experience and standards for all nuclear operations. These departments are responsible for monitoring and analyzing performance data from all stations in the areas of worker safety, public safety, environmental protection, product reliability, product cost and manpower development. Central Nuclear Services also conducts formal annual performance reviews with the manufacturers of major plant equipment.

Radioactivity Management and Environmental Protection Department reviews all Significant Event Reports related to worker safety, public safety and environmental protection. This review comprises an assessment of safety significance of the event and identification of implications for other Ontario Hydro nuclear generating stations. When safety implications are identified, they are communicated to the relevant station so that corrective action can be taken.

Internal audits of station activities are carried out periodically and the AECB conducts regular audits of station quality assurance programs. All results are reported promptly to the station manager.

Hydro's nuclear designers, safety analysts and researchers also play important roles in ensuring that experience gained through day-to-day operations is reflected in design changes to existing and future stations.

As detailed in the section on AECB regulations, page 19, the Canadian approach to nuclear safety puts the onus on the owner/operator of a nuclear station to demonstrate to the regulatory authority that the station's design and operating procedures continue to meet licensing requirements.

Ontario Hydro's Nuclear Studies and Safety Department continually reviews design performance and operating procedures to ensure that the reactors meet the highest possible safety standards. They must meet the AECB's requirements as well as Hydro's own.

As each successive nuclear station in Ontario was committed, safety and safety-related systems were updated, based on the latest information, technology or updated regulations. Some of these improvements were, or are being, retrofitted to operating nuclear stations, specifically where significant improvements in safety might result.

For example, after extensive study of the efficiency of the original emergency core coolant injection system in the Pickering reactors, Hydro decided the safety margin could be improved by replacing it with a high-pressure system. All eight reactors have been retrofitted. Hydro also recently increased the number of shut-off rods in Pickering units 1 and 2, and plans to make this change to units 3 and 4 in the near future to upgrade their shut-off capability.

In some instances, updated designs are not backfitted to earlier units because the existing systems have continued to demonstrate acceptable safety performance. A case in point is the single shutdown system in Pickering A, which consists of both gravity drop shut-off rods and moderator dump, both triggered by the same triplicated set of trip signals. This arrangement provides speed, depth and diversity in the shutdown mechanism, and has shown a very high level of reliability in tests since 1971.

Nuclear design and analysis work is based on two kinds of safety analysis. The *probabilistic approach* uses sophisticated computer programs to establish the statistical likelihood of the occurrence of many types and combinations of accidents.

The deterministic approach examines the consequences to the reactor system, environment and public of the postulated accident scenarios. The AECB has to be satisfied that the offsite consequences of any accident will not exceed its limits of radiation exposure to members of the public.

To ensure the margin of safety is adequate, deterministic evaluations postulate those failures (or combinations of failures) which pose the greatest challenge to the safety systems. This is done not because such events are believed highly probable, but simply because they pose the toughest demands on the safety systems. It is also assumed for analysis purposes that for the first 15 minutes of any accident the operators will take no corrective action and that weather conditions are the worst possible. The accuracy of deterministic evaluation is continually reviewed, in light of new operating experience, information about reactor problems elsewhere in the world and Hydro's own safety research and development.

Analyses by Hydro's Nuclear Studies and Safety Department incorporate data from research and development work conducted by Hydro's Research Division, Atomic Energy of Canada Limited (AECL) Research Company, and other agencies. Recent studies examined the chemistry of radioiodine, the behavior of aerosols (small solid and liquid particles suspended in a gas), the performance of radiation filters and the consequences of pressure tube and calandria tube failures.

Hydro also reviews operating experience from other utilities and applies the lessons learned to its own program. Good communications with other CANDU owners, the Institute of Nuclear Power Operations (INPO) in Atlanta, and the International Atomic Energy Agency (IAEA) in Vienna facilitate this task.

In Canada in 1988, $83 million will be spent on nuclear research in the areas of safety, pressure tube metallurgy and waste disposal. Ontario Hydro will fund $43 million of the research; AECL, $37 million; an additional $3 million will come from New Brunswick Power and Hydro Quebec. All the data will be available to Ontario Hydro.

Channel Rehabilitation

Channel Rehabilitation

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Channel Rehabilitation

Channel Rehabilitation

Channel
Rehabilitation

Fuel Channel Rehabilitation Programs

As with any machinery, Ontario Hydro's CANDU reactors will require more maintenance as they age. Much of it will involve the reactors' fuel channels, particularly in the earlier reactors, which have a number of overlapping fuel channel problems. These have been corrected in the design of more recent reactors.

In each Pickering A reactor, there are 390 fuel channels. Pickering B reactors have 380. All reactors at Bruce and Darlington have 480.

The chart on page 38 summarizes the characteristics of the fuel channels in all Ontario Hydro reactors.

Creep

All metals bearing heavy loads tend to "creep", or become thinner and longer, over time, from the weight they are carrying. In pressure tubes, this tendency is exacerbated by the neutron bombardment and high temperatures the tubes endure. Creep manifests itself in three ways in pressure tubes: they elongate, they increase in diameter and they sag, growing closer to the calandria tube. The rate of creep varies from tube to tube within a reactor.

Design allowances for creep elongation have been increased in all reactors built after Bruce 2: Pickering B, Bruce 3 and 4, Bruce B, and Darlington. The increase was inadequate, however, in Bruce 3.

For those reactors with inadequate room for creep, a maintenance program called "on bearing shift" has been developed: The bolt holding the end fitting is loosened so that it, and the pressure tube attached to it, slide a little further out of the reactor face. The bolts are retightened in this new position. On bearing shift was done at Pickering units 1, 3 and 4. It was scheduled for unit 2 but before it was performed, a pressure tube ruptured and the decision was made to retube the unit. On bearing shift was completed at Bruce unit 1 in February 1987, and at Bruce unit 2 in September, 1987. The procedure is scheduled for unit 3 in 1988: While this reactor has the adequate elongation allowance, it has incorrectly spaced garter springs (see below).

Another program, Repositioned End Fittings and Bearings (REFAB), is being considered for Bruce units 1-3 in the 1990s to provide more space for tube elongation.

Sag

The pressure tube is separated from the calandria tube by spacers called garter springs. As the tube sags between the spacers, it can come into contact with the calandria tube and the calandria tube itself can sag. This is more likely to happen in pressure tubes which have only two garter springs, those in Pickering units 3 and 4 and Bruce units 1 and 2. Reactors built after those have four garter springs per fuel channel.

But in some channels in some reactors, the four garter springs are incorrectly spaced. They probably moved during construction or commissioning of the reactor. If the garter springs are in the wrong place, the likelihood of sag causing early contact between pressure tube and calandria tube is increased.

A program to reposition garter springs without dismantling fuel channels has been completed in reactors which were not yet in service when this problem was identified: Pickering B units 7 and 8 and Bruce units 5, 6 and 7. Bruce unit 8, the four Darlington units and the newly-retubed Pickering units 1 and 2 have an improved garter spring design which precludes garter spring movement from the design location.

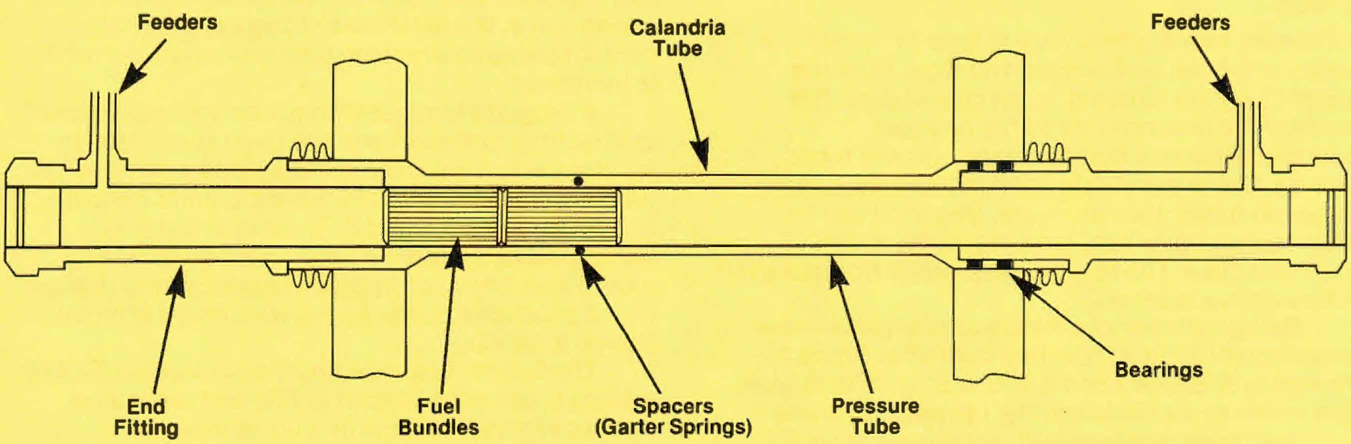
The Spacer Location and Repositioning (SLAR) project is being developed to find and reposition displaced garter springs in units which were operating prior to 1985. It is estimated that garter springs in up to 70 per cent of the fuel channels in Bruce 1, 2, 3 and 4 may require repositioning.

Atomic Energy of Canada Limited (AECL), New Brunswick Power, and Hydro-Quebec are participating in this project.

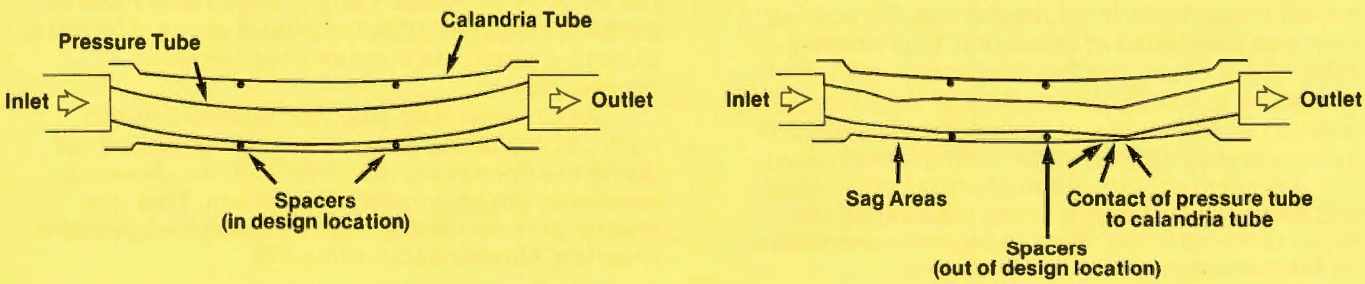
The first SLAR procedure is scheduled for Bruce 3, in the summer of 1989. The program may not be done on Bruce 1 and 2, which only have two garter springs per tube, because it may not be cost-effective, since the number of spacers is inadequate.

As of December 1987, the cost to Ontario Hydro of the SLAR project, including the cost of doing the necessary research and tool development was approximately $46 million. This is a capital program and so will be amortized over the reactors' 40-year accounting life.

A Fuel Channel



Creep/Sag, Contact and Garter Spring Displacement in a Two-Spacer Fuel Channel



Hydride Blisters

The pressure tube absorbs deuterium from the heavy water in the heat transport system. Up to a certain concentration of deuterium, there is no significant effect on the properties of the tube. However, as more deuterium is absorbed beyond this known level, the tube becomes more brittle. As well, should the pressure tube sag into contact with its surrounding calandria tube (which is much cooler) the deuterium in the pressure tube will migrate to the cold spot, causing blisters to form on the metal, weakening it and in some cases, leading to cracks along the blister line. The rate of deuterium uptake is considerably lower in reactors with zirconium-niobium pressure tubes, compared to the Zircaloy-2 used in Pickering units 1 and 2. The name hydride blisters comes from the word hydrogen; deuterium is an isotope of hydrogen.

Tube Replacement Because of Installation Method

Installation procedures used in the Pickering A units and Bruce A units 1 and 2 left high residual stress in the pressure tubes where they joined the end fittings. This "rolled joint" problem led to hydride cracking in and replacement of 69 tubes in Pickering 3 and 4, between 1974 and 1976, and three tubes in Bruce unit 2, in 1982.

Pressure Tube Replacement Program— Pickering 1 and 2

On August 1, 1983, one of the 390 pressure tubes in unit 2 at the Pickering station failed, resulting in a major leak of heavy water from the heat transport system into the reactor vault.

All 390 pressure tubes in Pickering units 1 and 2 have been replaced. Unit 1 returned to service September 14, 1987, and unit 2 is expected back in the fall of 1988.

Analysis done after the leak revealed that the Zircaloy-2 pressure tube had cracked after developing hydride blisters at several points where it had sagged into contact with the calandria tube.

The cost of tube replacement, including interest during construction, is being treated as a capitalized addition to the units, to be recovered during the remaining part of their 40-year service life. Because of the nuclear payback agreement covering these two units (page 46) only about one-third of the interest and capital costs will have to be recovered through electricity rates.

Pressure Tube Replacement Program— Pickering 3 and 4

The board of directors decided in March 1988 to advance the retubing of these units from the late 1990s to 1989 and 1991.

Since the Pickering 2 pressure tube rupture in 1983, Hydro has been conducting a Fuel Channel In-Service Inspection Program (ISI), under which a number of pressure tubes from operating reactors have been removed and examined.

Analysis of a tube pulled from Pickering 3 in August 1987 revealed concentrations of deuterium which were above the predicted levels at certain points along the length of the tube. While far lower than the levels in the Pickering 1 and 2 Zircaloy-2 tubes, the levels were judged to be close to the minimum threshold level for blister formation.

The increasing deuterium level is made more significant in Pickering 3 and 4 fuel channels because there are only two garter springs and some of the pressure tubes are known to be touching their calandria tubes.

In addition, because of the creep phenomenon, the pressure tubes in Pickering 3 and 4 will have increased in diameter to the limits of the bearings by 1989 and 1990, respectively, and will require REFAB. It is more economic to replace the tubes when they reach the end of their bearing allowance in units with two garter springs per tube than to relocate spacers and perform REFAB.

Pickering 3 will be removed from service for retubing in mid-1989 and is expected back in service 23 months later.

Once Pickering 3 is back in service in 1991, Pickering 4 will be retubed, in a process which is expected to take 19 months.

The cost of retubing the two units is estimated at $408 million in 1988 dollars, $500 million in escalated dollars. Retubing is a capital expense, to be recovered through electricity rates over the remaining service life of the reactors.

Fuel Channel Characteristics

	Pickering									Bruce									Darlington			
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8		1	2	3	4
Zircaloy-2 pressure tube	X	X																				
Zirconium-niobium pressure tube			X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X
Two garter springs	X	X	X	X						X	X											
Four garter springs					X	X	X	X				X	X	X	X	X	X		X	X	X	X
Springs repositioned before startup							X	X						X	X	X						
SLAR done or likely to be done					X	X						X	X									
Improved garter spring design																	X		X	X	X	X
Rolled joint problem in			X	X						X	X	X	X									
On-bearing shift										X	X	X										
REFAB being considered for										X	X	X										
Increased creep allowance in					X	X	X	X				X	X	X	X	X	X		X	X	X	X
Retubed	X	X																				
Retubing advanced for			X	X																		

Byproducts

Byproducts

Byproducts

By-Products

Cobalt-60

Ontario Hydro manufactures Cobalt-60 in its reactors for sale to Atomic Energy of Canada Limited (AECL), which ships it to more than 80 countries. Eighty-five per cent of the Cobalt-60 used in the world comes from Ontario Hydro reactors. Each year, 21 million curies of Cobalt-60 are transported by truck to AECL's Radiochemical Company in Kanata, Ontario in packages licensed by the Atomic Energy Control Board (AECB).

A gamma-emitter, Cobalt-60 is used in radiation therapy for cancer patients (500,000 patients around the world have this therapy each year). While linear accelerators are replacing cobalt therapy, the decline of that market is more than made up by increases in new industrial applications for the radioisotope, such as inspection of metal parts, medical sterilization and food irradiation. Virtually all disposable medical equipment, such as sutures, needles, surgical gloves, as well as many pharmaceuticals, are sterilized by Cobalt-60 irradiation.

At the Pickering A and B stations and at the Bruce B station, the vertically-mounted adjuster rods (see page 11) are made of non-radioactive Cobalt-59, encased in a stainless steel cladding. After a year of irradiation in the reactor, much of the Cobalt-59 has turned into Cobalt-60. When the reactors are shut down for maintenance, the adjusters are transferred to the fuel bay where the Cobalt-60 is removed. New Cobalt-59 adjuster rods are installed in the reactor.

Tritium

Unlike Cobalt-60, tritium is an unintended byproduct of the operation of a CANDU reactor. It is a radioisotope of hydrogen created through the irradiation of heavy water, which occurs because of the proximity of the moderator and heat transfer fluid to the nuclear fuel. Since tritium has a half-life of 12.5 years, it is created more quickly than it decays. Unless tritium is removed from the heavy water, the working environment for atomic radiation workers gradually becomes more radioactive. High concentrations of tritium in heavy water also mean that emissions from the plant would be more radioactive than if the tritium were removed.

Ontario Hydro has built a tritium removal facility at the Darlington Nuclear Generating Station. Scheduled to open in the fall of 1988, it is only the second plant of its kind in the world. The plant will process more than two million litres (440,000 gallons) of heavy water a year from Hydro's operating CANDUs. The water will be transported to Darlington on flatbed trucks in AECB-licensed casks built to international standards. Once the facility begins operation, one truckload of tritiated heavy water will arrive at the facility and one truckload of detritiated heavy water will leave it each week day. About 2.5 kilograms (5.5 pounds)of tritium will be extracted each year. It will be stored at the site, in cylindrical containers resembling fire extinguishers.

Ontario Hydro is studying the possibility of selling its waste tritium for use in luminescent signs and lights, as a fuel for fusion energy, and for medical use as a tracer substance in cell research. Hydro recognizes that tritium can also be used in nuclear weapons. For this reason, Hydro's board of directors will not approve tritium sales unless it and the provincial and federal governments are assured that tritium sold could not be diverted from its intended peaceful uses. All sales would be in accord with the federal Atomic Energy Control Act, the External Affairs Export and Import Permits Act and the regulations set by importing countries. Importing countries would have to be signatories of the Nuclear Non-Proliferation Treaty or have equivalent bilateral agreements with Canada. In addition, each sales contract would provide additional safeguards through regular Hydro inspection and audit of the buyers' facilities and records.

A Hydro Board of Directors' decision on tritium sales is likely in 1989.

Nuclear Waste

Nuclear Waste

Nuclear Waste

Nuclear Waste

Low and Intermediate Level Waste

Low-level nuclear wastes are often called housekeeping wastes and include such items as contaminated mops, plastic sheeting and protective clothing. They may be compacted or incinerated to reduce their volume, and are then stored at the Bruce Nuclear Power Development.

Used parts of the reactor system, such as replaced valves and filters used to decontaminate heavy water, are called intermediate level wastes. Their volume is reduced, if possible, before they are stored. Depending on the specific characteristics of low and intermediate level wastes, they are stored in concrete buildings, in dry storage modules or in in-ground containers at the Bruce site. The one exception to this is the pressure tubes removed during the retubing operation at Pickering. These are being stored in concrete containers at that station.

The major radioactive components of the vast majority of low and intermediate level nuclear wastes are cobalt and cesium, which have half-lives of five years and 30 years, respectively. After 300 years, they can be disposed of as conventional wastes would be—radioactivity is no longer a problem. The exceptions are the filters from the moderator and primary heat transport systems, which contain a wide range of long-lived radioisotopes.

The costs associated with managing these wastes are part of Hydro's operating expenses and are included in electricity rates.

Used Nuclear Fuel

This is the most highly-radioactive material Ontario Hydro deals with. More than 99 per cent of the radioactivity in a nuclear station is in the fuel bundles.

Each fuel bundle is in the reactor for about 15 months. When removed, it looks the same as it did when it went in. But it has become highly radioactive through fission and irradiation.

Because of the radiation it emits, used fuel requires both cooling and shielding. At present, these requirements are met by storing the fuel in water-filled bays at each nuclear station. Fuel handling, including storage, is explained in CANDU Design, page 14. Underwater storage is considered safe for at least 50 years.

Future Storage and Disposal

Under the terms of the 1978 Canadian Nuclear Fuel Waste Management Program, Ontario Hydro has responsibility for developing interim fuel storage and fuel transport technologies while Atomic Energy of Canada Limited (AECL) studies permanent fuel disposal.

It is estimated that the number of used fuel bundles—currently more than 300,000—will increase five-fold by the year 2000. Additional storage facilities will be needed by the mid-1990s. New fuel bays could be built next to existing bays, and dry above-ground interim storage is also being studied by AECL and Ontario Hydro.

Permanent disposal is being studied at the Whiteshell Nuclear Research Establishment at Pinawa, Manitoba. Experiments are underway to determine the feasibility of burying fuel in ancient rock formations, known as plutons, in the Canadian Shield. Plutonic rock is between one and two billion years old and has changed little in that time.

An underground repository would be inaccessible. Fuel buried deep in the rock would pose no more hazard to a person on the surface than would a typical uranium orebody. All radiation coming from the fuel would be absorbed by just a few metres of rock.

The fuel would be packed in containers designed not to corrode or leak for at least 500 years. This would prevent radioactivity from leaching into underground water. Any radioactivity which might enter underground water after 500 years would be no more significant by the time it reached the surface than that from a natural uranium deposit. This is because any radioactivity would be diluted in the water and because water moves slowly through plutonic rock, allowing time for some isotopes to decay.

One of the AECB requirements for approving a repository is the submission of analyses demonstrating that changes in underground water, geology and fuel composition and migration over 10,000 years would not pose an unacceptable risk to humans.

Transportation

Transportation of low, intermediate and high-level waste is discussed under Transportation of Radioactive Materials, page 22.

Decommissioning

Decommissioning

Decommissioning

Decommissioning

Ontario Hydro's nuclear stations have an accounting life of 40 years; they are amortized over that period. Since 1982, Hydro has used the internal sinking fund method to accrue funds for the safe dismantling of nuclear stations (expected to cost 10 percent of the construction cost in constant dollars).

With good maintenance and refurbishing, the reactors may last longer. The CANDU system is a component system, so parts can be replaced as needed. This has recently been demonstrated with the retubing of Pickering units 1 and 2 (see page 37).

By the middle of the next century, a new electricity-generating technology might be able to replace Hydro's nuclear plants. New facilities could be built on the same sites, or the sites could be released for other uses. The former possibility is more likely, since nuclear plants are located on ideal sites for other facilities and are well-tied to the transmission system.

The International Atomic Energy Agency (IAEA) has set procedural guidelines for decommissioning. Hydro would require AECB licenses meeting those standards for all phases of decommissioning and for all transportation of resulting radioactive wastes.

If desired, all traces of a station could be removed using a three-phase, 40-year decommissioning program:

Phase I

Fuel would be removed from the reactor and kept in an on-site storage bay for 10 years until it could be transported safely to an approved storage or disposal facility. The heavy water systems would be drained and the water transported to storage, or to other stations for continued use. Piping systems would also be decontaminated. These measures would reduce the long-lived radioactivity at the site by more than 98.5 per cent. Regular monitoring would continue throughout this phase which would take two to three years.

Phase II

This involves storage with surveillance, lasting about 30 years, to allow the radioactivity in the station to decay to lower levels. During this phase the used fuel would likely be moved from the station.

Phase III

All radioactive components would be dismantled and moved to a central storage site, and all buildings would be demolished. The site would be backfilled and all traces of the station would be eliminated. This would take about eight years.

Nuclear Costs

Nuclear Costs

Costs of Coal and Nuclear Compared

Bruce Nuclear Generating Station-B and Comparable Coal-Fired Station Cost Comparison—1987

Total Unit Energy Cost (TUEC) $/MW.he (Net)

	Bruce NGS-B	Comparable Wet Scrubber Coal-Fired Station*
	(3.6 unit-years)	(3.6 unit-years)
Interest, depreciation and decommissioning**	31.6	25.5
Operation, maintenance, and administration***	3.6	3.6
Fuelling****	5.8	22.2
Heavy water upkeep	0.3	—
Total unit energy cost (Net)	41.3	51.3

Station Data

	Bruce NGS-B	Comparable Wet Scrubber Coal-Fired Station
1987 Energy output (TWhe)	22.5	22.5
1987 Net capacity factor (%)	84.8	84.8
Capacity (maximum continuous rating) MWe net	4 X 837	4 X 837
Forecast in-service period	1984-1987	1984-1987
Forecast original capital cost (M$ Canadian escalated)	5 963	4 014
Specific capital cost ($/kWe)	1 782	1 199
Economic lifetime (years)*****	40	35
Depreciation method	Straight Line	Straight Line
Interest rate (%)	12.4	12.4

* Assumes that the comparable coal-fired station would have been equipped with wet scrubbers and would have been operated as a base load station with Bruce NGS-B 1987 Net Capacity Factor of 84.8%. Wet scrubbers account for less than 15 per cent of the total unit energy cost.

** Since 1982, Hydro has used the internal sinking fund method to accrue funds for the safe dismantling of nuclear stations (expected to cost 10 per cent of the construction cost in constant dollars). Ontario Hydro similarly makes provision for future pressure tube removal costs at its nuclear stations.

*** The operation, maintenance and administration budget of a nuclear station includes the cost of running Hydro's fuel storage bays.

**** Provision is also made in the fuelling budget for the eventual transportation and disposal of irradiated fuel using the internal sinking fund method.

***** Construction costs for Ontario Hydro's reactors are amortized over 40 years. All capital projects undertaken after the station is operating, such as the retubing of Pickering 1 and 2, are also depreciated (amortized) by the end of the 40 year period.

Nuclear Payback Agreement

Because Pickering 1 and 2 were the first large-scale commercial power reactors in Canada, Hydro, the Province of Ontario and Atomic Energy of Canada Limited (AECL) shared the uncertain economic responsibility of building the two reactors. The three parties shared the capital costs of construction and agreed to share the economic advantage, or disadvantage, of producing electricity from these two nuclear units compared to similar coal-fuelled units. Because the units proved more economical than coal-fired units, payments totalling about two-thirds of the relative benefit (called payback) are made by Hydro to the other two parties each year.

As a result of the payback agreement, the cost of replacing the pressure tubes and providing replacement energy during the retubing outages is shared by the three parties through reductions in the payback. Since late 1983, the value of the payback has been negative, and it is expected to remain negative until about the time both units are returned to operation. For accounting and rate-setting purposes, this negative payback is included as a credit to costs, and therefore helps to offset some of the costs associated with retubing.

Negative payback is not being collected by Hydro from the other two parties. A recent amendment to the payback agreement provides that Hydro recover this accumulated negative payback, including interest, from the other two parties over the remaining life of the agreement, once the two units are back in commercial operation. The amendment also calls for an extension of two years to the agreement to the year 2003.

Nuclear Insurance

Under the provisions of the Nuclear Liability Act, which took effect October 11, 1976, Ontario Hydro, as owner and operator of nuclear power generating stations, is required to maintain nuclear liability insurance of $75 million on each of its operating nuclear stations.

This coverage is intended to meet claims by citizens in the event of a nuclear accident. No funds are provided for the repair of damaged Hydro facilities, since this is strictly third-party liability coverage. No nuclear accidents with off-site consequences have occurred and no claims have ever been received by Ontario Hydro in more than 20 years of nuclear operating experience.

The Atomic Energy Control Board (AECB) recommends to the Treasury Board the amount of insurance for each nuclear installation; $75 million in Hydro's case. The Nuclear Insurance Association of Canada (NIAC), a consortium of several insurance companies licensed to do business in Canada, is the sole source from which an operator may purchase nuclear liability insurance. Two factors the NIAC takes into account in determining annual insurance premiums are population density and property values near each nuclear station. The cost of annual premiums is reflected in Hydro's rates.

The approximate insurance premiums paid by Ontario Hydro for operating stations in 1988 were:

Pickering A and B†	$1,064,000
Bruce A†	$ 323,500
Bruce B†	$ 323,500
NPD Rolphton*	$ 33,000
Total	$1,744,000

†Pickering is considered one station, because all units share common services, and so it is insured for $75 million. Bruce A and B are two distinct stations because of their geographic separation and so are insured for $75 million each.

*Recovered from AECL as owner of the nuclear portion of the station. AECL and Ontario Hydro decided to close the station July 24, 1987, but it is still under AECB license and therefore must be insured.

The Nuclear Liability Act specifies that in the event of a nuclear accident where claims are expected to approach or exceed $75 million, a nuclear damage claims commission will be established to settle all claims. Settlement of claims exceeding $75 million must be authorized by Parliament.

The Act specifies that a claimant need only prove the injury or damage was caused by the nuclear accident at the operator's facility. The operator may not sue suppliers of fuel and components.

The Act also determines responsibility for injury or damage inside Canada as a result of a nuclear accident involving nuclear material in-transit to or from a nuclear installation in Canada.

Federal legislation is being reviewed to determine whether it is still appropriate.

Comparison of International Liability Levels

- *France*—A nuclear operator is liable for $5.9 million (Canadian) per accident, with the government liable for up to $74 million.
- *England*—A nuclear operator is liable for $10.1 million, with the government liable for $277.5 million.
- *Sweden*—The nuclear operator is liable for $55.5 million, and the government for $336 million.
- *United States*—Passed in 1957, the Price-Anderson Act requires U.S. nuclear operators to maintain third-party liability coverage of $705 million. Private insurance is available to a limit of $160 million. The balance would be paid following an accident according to a formula under which each electric utility would pay $5 million for each reactor it operates (based on 109 operating reactors) to settle claims. The Act expired August 1, 1987, but its provisions still apply until Congress passes legislation to extend it.

  A bill extending the legislation was passed by the House of Representatives in mid-1987. It raises the nuclear plant liability limit to about $7 billion. Under the legislation, utilities will carry the private insurance available ($160 million), and would pay $63 million per reactor, in annual installments of $10 million, into a compensation fund after an accident.

  The Senate passed the bill in March 1988, after adding several key amendments to the House version. The Senate version extends the Act for 20 years, rather than 10 years; allows the Department of Energy to impose civil or criminal penalties against contractors or their employees for wilful violation of safety rules (certain universities and non-profit contractors would be exempt); includes nuclear pharmacies and radio-pharmaceutical manufacturers; allows the Department of Energy to be sued for nuclear waste accidents caused by its own employees.

  No date has yet been set for reconciliation of the Senate and House versions of the bill before the Conference Committee.

How Nuclear Power Plants are Financed

Ontario Hydro finances capital expenditures, including nuclear power plants, primarily through bonds it issues in its own name in the Canadian public bond market. Hydro bonds are guaranteed by the provincial government.

Rather than have today's customers pay for construction projects which will not be generating electricity for years, Hydro issues bonds to cover building costs. Only when the asset is declared "in service" do the costs of its construction figure into the rate base. In this way, the customers who use the power from a particular station pay for the construction of that station.

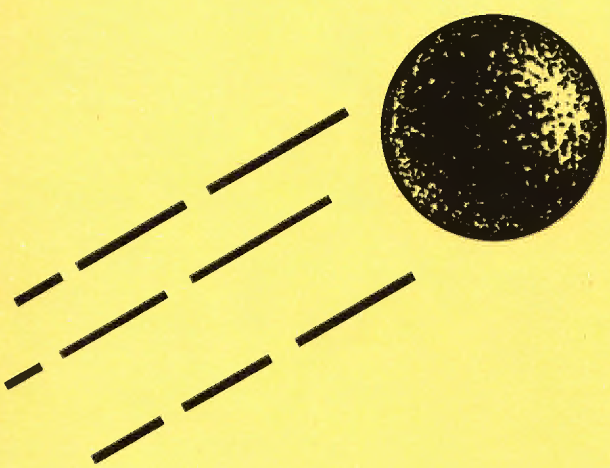
Increasingly, current borrowings are being used to refinance past borrowings, since the term of past borrowings has been shorter than the time required to recoup construction costs.

At the end of 1987, Hydro's total liabilities were $25 billion (of which $23.8 billion was long-term debt) balanced by assets of $32.6 billion. The replacement cost of these assets would be approximately $45 billion.

Ontario Hydro has the third strongest debt to asset ratio of all Canadian provincially-owned utilities. Hydro-Quebec's is the best, followed by that of Newfoundland and Labrador Hydro.

Hydro's total dollar debt is roughly 35 per cent American dollar, 10 per cent Eurodollar (U.S. dollars borrowed in Europe) and 55 per cent Canadian.

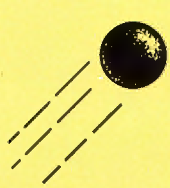
Principles Behind The Power



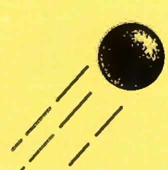
Principles Behind The Power

Radiation

Radiation



Radiation



Understanding Radiation

Among scientists, more is known about radiation and its attendant risks than about most other physical and chemical agents in our environment. Little of that understanding has reached the non-scientific world.

Radiation is one of the most pervasive and widely misunderstood phenomena in the world. A vast number of dissimilar things fit under the radiation umbrella: It is the generic descriptive used for everything from the workings of a microwave oven to the power source of a nuclear plant to the healing effects of a spring-fed spa.

You can't taste it, smell it and usually can't see it; another reason for the difficulty of understanding what radiation is.

The world is made up of substances composed of various configurations of atoms. Radiation is stimulated by actions occuring among particles smaller than atoms. To understand the human-scale consequences of radiation, one has to first understand what happens on the sub-atomic level.

The best definition we can find is: **Radiation is energy travelling through space, as waves or with particles.**

Energy travelling as waves—electromagnetic radiation—has no mass. Obviously, energy travelling with particles—particulate radiation—has mass.

The force of a gust of wind or of a torrent of hailstones can knock a pedestrian off his feet: One meteorological hazard has mass, the other does not. Without attempting to explain the weather (radiation is simpler!) it is apparent that something set the energy in motion that, through the wind or hail, knocked the pedestrian down.

Similarly, something must set in motion that energy that is radiation. Electromagnetic radiation can be excited by a number of things, two of the most common in our world are the sun and radio-transmitters. Particulate radiations are, most commonly, subatomic fragments given off by radioactive substances.

One of the distinguishing characteristics of all radiations is that they can be easily monitored and measured. Radioactive dust in a soil sample, for instance, can be measured by holding a simple Geiger counter over the soil. To determine if there is arsenic in the same sample, a chemical analysis would have to be done, more time consuming, if not more expensive.

The danger of radiation to living things spans the whole range of possibilities. Most of the slower-speed waves are not hazardous, certainly not in the amount of contact the average person has with them. Coming into contact with substances emitting radioactive particles poses some danger. But the danger varies greatly, from virtually non-existent, such as that in taking a medical test like a barium swallow, to fatal, as in prolonged, unprotected exposure to highly radioactive metal.

This chapter moves from an explanation of radiation theory to a discussion of the biological effects and practical risks of radiation exposure.

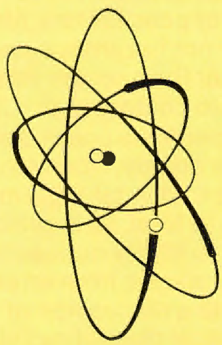
Certain electromagnetic radiations and particulate radiations can be called rays—alpha rays and gamma rays, for example. We have avoided reference to rays wherever possible to avoid confusion between these two distinct phenomena.

Atomic Theory

Atoms are the building blocks of matter. Physicists are discovering more and more particles within the atom, but atomic theory still hinges on the role played by the protons, neutrons and electrons.

The nucleus of an atom consists of protons, which have a positive charge, and neutrons, which have no charge. Orbiting around the nucleus are electrons, which have a negative charge.

Atoms of different elements contain varying numbers of protons, neutrons and electrons, but usually the number of negatively-charged electrons balances the charge of the larger, positively-charged protons, so the atom has no net electrical charge.



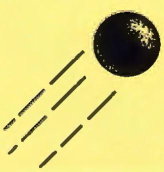
Elementary Forces and Radiation

There are four elementary forces in nature. All but one, gravitation, play a part in radiation.

Electromagnetic force: a positive and a negative force attract each other; two positives or two negatives repel each other.

Strong nuclear force: along with the electromagnetic force, this holds the particles in the atom together.

Weak nuclear force: the force which splits radioactive atoms.



Radiation As Waves
Electromagnetic Radiation Defined

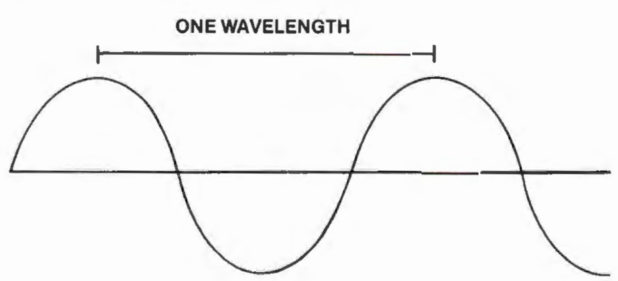
Electromagnetic radiation is energy moving through space or a material medium as waves.

It is released when the electromagnetic force in the atom changes, accelerating the movement of the particles which comprise it. The faster the particles move, the more energy escapes from the atom.

This atomic activity can occur in radioactive atoms. But most kinds of electromagnetic radiation occur when non-radioactive atoms come into contact with an external stimulus, such as electric signals.

Energy has no identifiable mass and no electrical charge but it travels in tiny packages, almost like particles, called photons. Any given quantity of energy, or photon of energy, travels at the speed of light (186,000 miles per second; 299,792 kilometres per second). All kinds of electromagnetic radiation travel at that speed in a vacuum.

Photons move through time and space in waves. The length of one wave, from highest point to lowest and up to the next peak, is called a wavelength. One wavelength corresponds to one vibration or one cycle.



The frequency of a wave of electromagnetic radiation is the number of cycles which occur in a second.

Scale of Electromagnetic Radiation

Extremely Low Frequency (ELF)

- 0-1,000 Hz frequency; shortest wavelengths are 300 kilometres (186 miles) long;
- transmission of 60 Hz electricity, the North American standard, creates ELF radiation, with wavelengths 5,000 kilometres (3,107 miles) long; it is caused by electric current scattered by the resistance of the line; the higher the voltage (pressure) at which the electricity is transmitted the fewer waves are emitted because the resistance of the line is a proportionately weaker obstacle to the flow of current;
- there has recently been concern that ELF radiation can cause cancer; data is inconclusive and contradictory but Ontario Hydro is studying employees who are exposed to ELF radiation to see if there are any health effects.

Radiowaves

Very Low Frequency (3-30 kHz)

- VLF wavelengths are between 10-100 kilometres (six-62 miles) long.

Low Frequency (30-300 kHz)

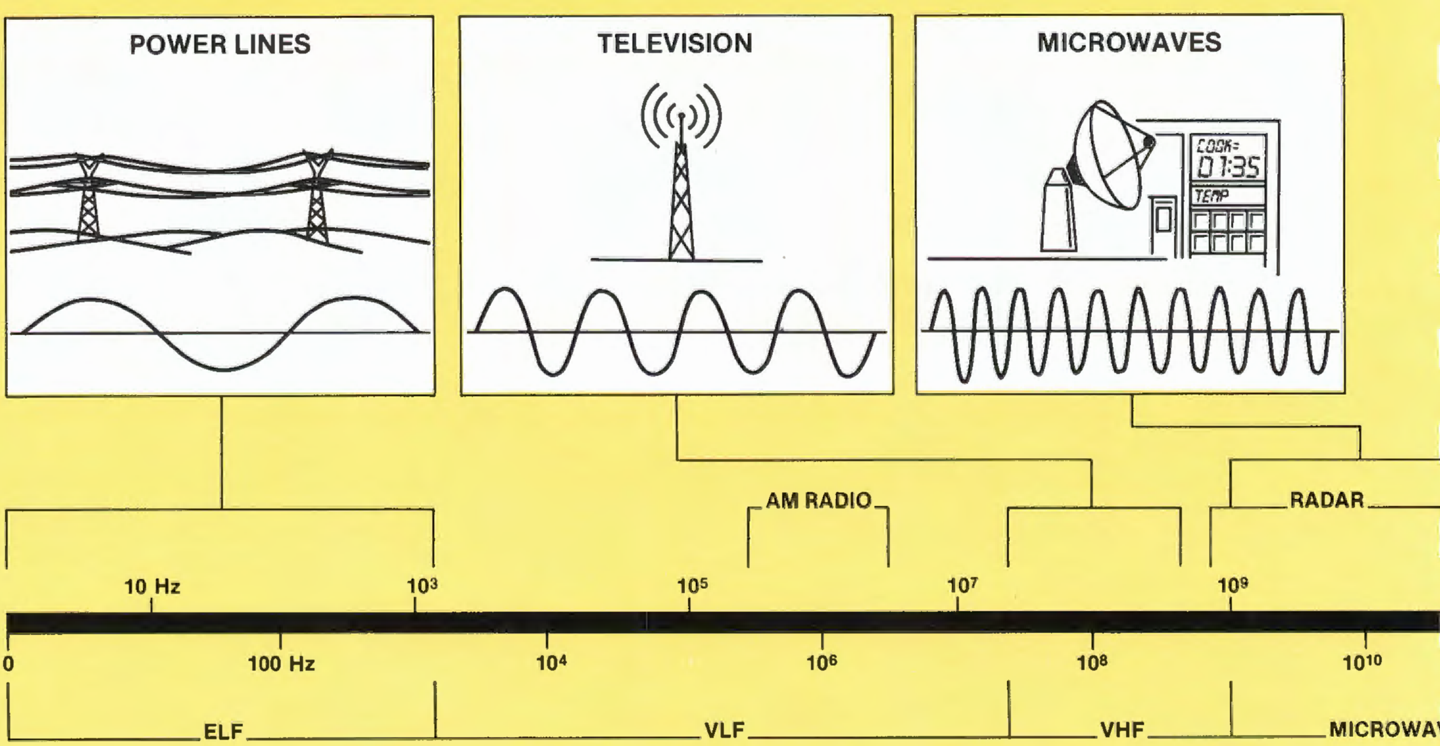
- LF wavelengths are 1-10 kilometres (1/2-six miles) in length;
- frequency used for telegraph and direction finding.

Broadcast—Medium Wave (500-1600 kHz)

- wavelengths are between 190-600 metres (623-1,970 feet) long;
- regular AM radio broadcasting frequency—sound is converted to electrical signals, transmitted as electromagnetic waves, received and converted back.

Shortwave (1.6-30 MHz)

- wavelengths 10-190 metres (33-623 feet) long;
- frequency for ham radio and international shortwave radio.



The above illustration is reprinted with permission from the *EPRI Journal*, October/November 1987.

Very High Frequency (30-300 MHz)

- VHF wavelengths are 1-10 metres (3.2-33 feet) long;
- TV and FM radio signals are this frequency (sound and light are converted to electrical signals, transmitted as electromagnetic waves, received and converted back);
- radar frequency.

Microwave (300-300,000 MHz)

- shortest wavelengths are 1 millimetre;
- used for long-distance communications on the ground (with microwave towers);
- used for satellite communication;
- used in microwave cooking—the wave penetrates the food, stimulating molecules, causing internal heat and thus cooking;
- used in radar and TV transmission.

Infrared Radiation

- a huge waveband (600 times wider than the visible band);
- beyond the red end of the visible light spectrum;
- any warm object, living or inanimate, emits these rays;
- they are emitted from heat lamps to treat sore muscles.

Visible Light

- the only electromagnetic radiation which the human eye can see;
- white light contains all wavelengths of light; each wavelength corresponds to a different color; from longest to shortest, they are: red, orange, yellow, green, blue, indigo, violet.

Ultraviolet Radiation

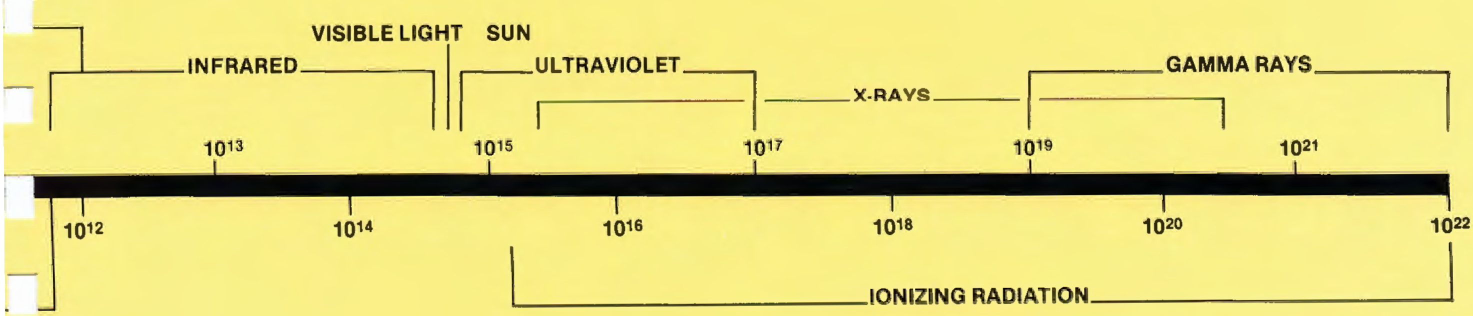
- a waveband beyond the violet end of the visible spectrum;
- emitted by the sun or electric arcs, it causes the skin to produce Vitamin D as well as to tan and burn;
- can cause ionization so implicated in causing skin cancer;
- can be used to kill germs;
- when man-made, often called black light.

X-Rays

- energy vibrating very quickly, it can pass through objects that visible light can't;
- naturally produced by the sun and stars;
- artificially produced in an X-ray tube by sending a stream of electrons through a vacuum onto a metal target;
- tremendous medical benefits for examining bones and muscles;
- can cause ionization (see page 58).

Gamma Rays

- can be described as very energetic X-rays;
- released from the decay of radioactive atoms (see page 57);
- very penetrating: some gamma rays can only be stopped by a metre of concrete or water or dense metals such as lead;
- used in medicine for cancer treatment, for diagnostic purposes and in industry for the inspection of casting and welds;
- can cause ionization (see page 58).



Radiation As Particles

Particulate Radiation Defined

Particulate radiation is energy travelling through space or a material medium as particles emitted from the nuclei of radioactive solids, liquids or gases.

The atoms of non-radioactive, or stable, elements (such as gold and mercury) always contain a constant level of electromagnetic energy. It is just enough to maintain the appropriate distance between the protons and the neutrons in the nucleus and the orbiting electrons. Since there is no surplus energy in the atom, it will remain stable unless it is stimulated externally to the point where the particles move more quickly and emit electromagnetic radiation.

In radioactive elements, however, the particles in the nucleus of the atom are not in harmonious relationship. They are being held in their proper atomic formation by the electromagnetic force and the strong nuclear force. But the weak nuclear force is trying to change them and pull them apart. This tension creates more energy than the atom can contain. The excess energy is emitted as alpha and beta particles and gamma rays.

Atoms of different radioactive substances emit different amounts and combinations of alpha and beta particles and gamma rays.

Particulate Radiation Classified

Alpha particle

An alpha particle is a helium nucleus: two protons and two neutrons which behave as a single particle with a positive charge.

An alpha-emitting atom has to have a large mass in order to generate enough energy to release such a tremendous particle (a single proton has 1,840 times more mass than an electron).

Despite its high-energy launch, an alpha particle is so heavy that it loses energy rapidly as it travels. It cannot penetrate a sheet of paper or through the outer, dead layer of human skin.

Beta particle

A beta particle is an electron. Beta particles can have a negative charge, as electrons do, or a positive charge, in which case they are called positrons.

Beta particles are emitted from most radioactive substances. Because of their small size, beta particles travel more quickly than alpha particles, with the most energetic beta particles travelling almost at the speed of light.

The penetrating capability of beta particles increases with their energy (velocity). Very energetic particles can penetrate one to two centimetres of human tissue. A three centimetre (one inch) thickness of wood will stop even the most energetic beta particles.

Neutron radiation

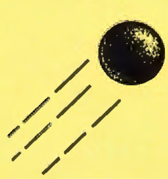
Neutrons are shot out of atoms during nuclear fission (see **Fission,** following) during fusion and in particle accelerators. A few radioactive elements emit neutrons during radioactive decay (see next page). A highly penetrating form of radiation, neutron radiation actually makes things radioactive (see **Irradiation,** page 58).

Decay Path of Uranium-238

An atom of U-238, an isotope of uranium, contains 92 protons and 146 neutrons. After emitting an alpha particle (two neutrons, two protons), the nucleus only has 90 protons and 144 neutrons left. It is no longer a uranium atom, but a thorium atom, $_{90}Th^{234}$. The uranium isotope has decayed into a thorium isotope.

One can trace the decay path of a radioisotope through a number of transmutations until it finally succeeds in becoming a stable element. Uranium-238, for example, ultimately becomes lead:

Type of Radiation Emitted	Element	Half-Life
	Uranium-238	4.47 billion years
alpha		
	Thorium-234	24.1 days
beta		
	Protactinium-234	1.17 minutes
beta		
	Uranium-234	245,000 years
alpha		
	Thorium-230	8,000 years
alpha		
	Radium-226	1,600 years
alpha		
	Radon-222	3.823 days
alpha		
	Polonium-218	3.05 minutes
alpha		
	Lead-214	26.8 minutes
beta		
	Bismuth-214	19.7 minutes
beta		
	Polonium-214	0.000164 seconds
alpha		
	Lead-210	22.3 years
beta		
	Bismuth-210	5.01 days
beta		
	Polonium-210	138.4 days
alpha		
	Lead-206	stable



Radioactivity Defined

Radioactivity is the spontaneous disintegration of the nucleus of an atom by expulsion of particles. It can be accompanied by electromagnetic radiation. Solids, liquids or gases can be radioactive.

Measuring Radioactivity

The "activity" of a radioactive substance is the rate at which it is disintegrating. The curie (Ci) is the unit for measuring the rate of this activity: the number of times particles are emitted from the nucleus in a minute:

1 curie = 2.22×10^{12} disintegrations per minute.

Because the curie represents a fairly high rate of disintegration, the sub units millicurie (mCi) and microcurie (μCi) are often used:

1 millicurie = 2.22×10^{9} disintegrations per minute
1 microcurie = 2.22×10^{6} disintegrations per minute

NOTE: The activity (number of curies) of a given sample will decrease over time as there are fewer nuclei left to disintegrate.

The world is moving toward adoption of the Système Internationale to standardize all sorts of measurement (metrication is part of this). The becquerel (Bq) is the unit of measurement which will replace the curie under this system:

1 becquerel = 1 disintegration per second

See page 94 for a conversion table.

Radioactive Decay Defined

Non-radiaoctive elements do not decay, or change into another element. Naturally-occuring mercury, for instance, is always mercury.

All radioactive atoms decay. Once a nucleus has released an alpha or beta particle, it contains a different number of protons. It is not the same atom: it has changed into an atom of another element or isotope*. This change is called radioactive decay or transmutation.

Once an atom has decayed into another element or isotope, it may still be radioactive. If so, it will decay into something else. The radiation emitted from this decay product might not be the same as that which was emitted when it was created. As the chart opposite illustrates, Uranium-238 emits alpha particles as it decays into Thorium-234. But Thorium-234 is a beta emitter.

* **Isotope:** Isotopes are atoms of the same element with the same number of protons but different numbers of neutrons. All isotopes of an element have the same chemical properties (i.e., they will combine with the same substances) but have slightly different physical properties (i.e., one will have greater mass than another). Most isotopes are man-made and are radioactive. Radioactive isotopes are called radioisotopes.

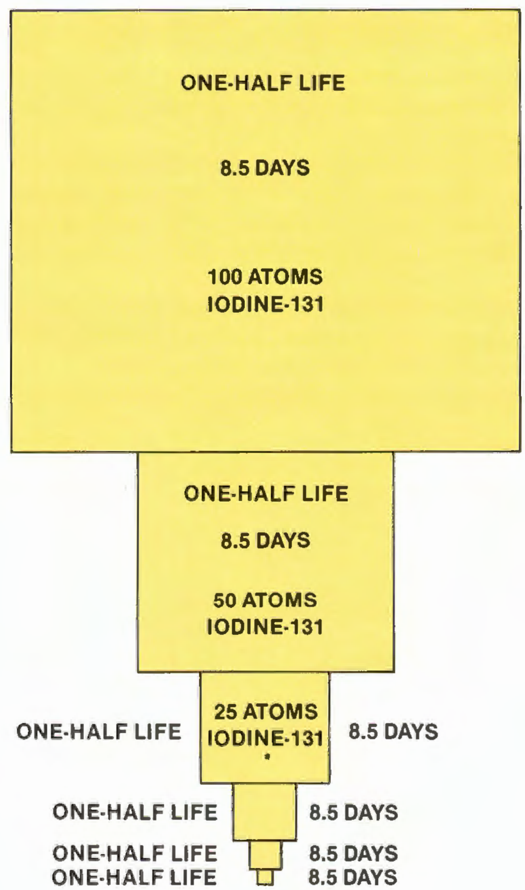
Half-Life Defined

Half-life is the unit of time used to measure the rate of radioactive decay. A half-life is the time required for half the atoms of an element or isotope to decay into another element or isotope. Some elements have a half-life of millions of years; others, of just a few seconds.

EXAMPLES:

Uranium-238:	half-life,	4.5 billion years
Plutonium-239:	half-life,	24,000 years
Strontium-90:	half-life,	29 years
Tritium:	half-life,	12.5 years
Iodine-131:	half-life,	8.5 days

Decay of Iodine-131



Ionizing Radiation

Irradiation Defined

Irradiation is the process of exposing an object or person to any kind of radiation.

As discussed in the next section, we are all irradiated in daily life, by sunlight, low-frequency radiowaves, cosmic rays, by radiation in other human bodies and bricks, among other things.

Neutron Irradiation Defined

When something is irradiated by neutron radiation, it becomes radioactive. That is how the metal used in building a reactor becomes radioactive and how the radioisotope Cobalt-60 is made in CANDU reactors (see page 39).

Ionizing Radiation Defined

The hazardous radiations are those which cause ionization: neutrons, gamma rays and alpha and beta particles.

An atom or group of atoms with a net electrical charge is called an "ion". This charge is acquired when an atom gains or loses one or more electrons or protons. Ionization is the process of creating ions.

When ionization happens to atoms in living tissue, it can change the chemical makeup of the tissue and lead to cancer and congenital malformations and, possibly, to genetic damage.

Paths of Exposure to Ionizing Radiation

Ionizing radiation can be emitted by radioactive solids, liquids or gases.

Ionizing radiations are all around us. The human body is exposed to ionizing radiation externally, for example, from touching or standing near radioactive rocks, from bathing in the water at a radioactive spring.

The inside of the body can also be exposed to ionizing radiations. They can be absorbed through the skin, inhaled, or ingested. The effect of internal irradiation can be compounded if the body treats the radioactive substance as a nutrient (see page 60).

The biological damage caused by ionizing radiation depends on the amount and type of exposure (see page 61).

Reducing Exposure— Time, Distance, Shielding

The less time one spends in the path of ionizing radiation, the less is absorbed, the less potential for injury. That is why the amount of time atomic radiation workers spend in highly radioactive parts of the plant is strictly controlled.

The further one is from the source of ionizing radiation, the less its effect.

All ionizing radiations can be blocked with the appropriate shielding; a several-inch thickness of material for alpha and beta particles, several feet of dense material such as lead or concrete, to stop neutrons or gamma rays.

Sources of Ionizing Radiation Exposure

Natural Radiation

There are three main groups of ionizing radiations which are a naturally-occuring characteristic of the earth and to which everyone is exposed: cosmic radiation; terrestrial radiation; and radon gas. While exposures can vary greatly, depending on where one lives, the average person in Ontario absorbs 220 millirem a year from these sources.

Cosmic radiation is composed of various subatomic particles—protons, neutrons, alpha particles, parts of the nuclei of carbon, nitrogen and oxygen atoms—which constantly bombard the earth. Secondary radiation is produced when these particles collide with molecules in the atmosphere. This causes the aurora borealis (Northern Lights). Some cosmic rays have energies a billion times greater than can be achieved in particle accelerators. The atmosphere shields us from much cosmic radiation so exposure is greater at higher altitudes where the atmosphere is thinner.

Terrestrial radiation comes from the elements that make up the earth. There are a number of "hot spots" in the world, notably in Brazil and India, where people have lived for centuries on radioactive monazite sands which give them an annual exposure of 1,000 to 5,000 millirem (equivalent to upper-range exposure limits for atomic radiation workers).

Perhaps the most significant terrestrial radiation is radium: All rocks and soil contain it. Radium enters the food chain through plants which absorb from the soil, because it reacts chemically like calcium (see next page). This is particularly pronounced in places where the calcium content of the soil is low.

Radium eventually decays into the alpha-emitting noble gas, radon. Decay products of radon, called radon daughters, emit gamma rays. Chemically inert, radon and its daughters are not metabolized by the body. In some countries, they account for over 60 per cent of the average individual's annual exposure to background radiation. Since they are present in rocks and soil and therefore building materials, the concentration of radon and its daughters tends to build up indoors, particularly in basements and super-energy efficient buildings that are not sufficiently ventilated. Outdoors, radon concentrations are highest at midnight in the winter and lowest at noon in the summer, because of the way radon mixes with the air at those times and temperatures.

Societal Radiation

Medical exposure to radiation in developed countries like Canada and the United States has become the largest single contributor to ionizing radiation exposure; currently it adds an average 100 millirem a year to each person's exposure.

Many consumer products contribute minute amounts to ionizing radiation exposure: among them, smoke detectors (Americium-241); colour television sets (X-rays); false teeth (uranium is used in dental porcelain to make it shine); self-illuminating lights and clocks and watches with luminous numbers (tritium); computer screens (X-rays); phosphate fertilizers (uranium and decay products); florescent tube lights (various radionuclides can be used as starters).

Through their work, many people such as miners, nuclear plant workers, radiology workers, airline crews, computer operators, are exposed to radiation. More people than in the past are receiving occupational exposure to radiation but in many fields where exposure can be controlled, improving safety procedures means the exposure per person is declining (this is occuring in Hydro's nuclear plants, see page 24).

Like all minerals, coal contains traces of radioactive elements: Potassium-40, as well as Uranium-238 and Thorium-232 and their decay products and radon daughters. When coal is burned, many of the radioisotopes it contains are released in the smoke. Radioiosotopes are more concentrated in the remaining ash than they were in the original coal.

Geothermal energy (harnessing underground reserves of steam and hot water) releases three times the radiation of burning coal.

Nuclear power, too, releases radioactivity to the environment. From living for a year at the boundary of an Ontario Hydro nuclear station, one would receive an additional 5 millirem (0.005 rem) exposure.

The building materials society favors—granite, gypsum, concrete made with ash left from burning coal—also contain radioactivity.

Fallout from above-ground nuclear tests conducted since 1945 contributes about two millirem a year to each Ontarian's exposure to radiation.

Other Living Things

From unavoidable exposure to the radiation all around us, people and animals pick up trace radioactivity and so become minute sources of radiation exposure to each other.

The principle radioactive elements in the human body are Potassium-40, Rubium-87, Carbon-14, Hydrogen-3 (tritium), Radium-226 and Thorium-232.

The Biochemical Properties of Radioactive Substances

Radioactive elements, which emit gamma rays, beta (strong and weak) and alpha particles, occur in solid, liquid and gaseous states. They react chemically like non-radioactive elements.

The body can't detect radioactivity, it metabolizes elements according to their chemical composition. So if a radioactive element which reacts chemically like an element is found in food and is inhaled, ingested or absorbed through the skin, the body will treat it like a nutrient, directing it to the organ (critical organ) where that nutrient is used.

The length of time radioactive substances are retained in the body varies according to normal body elimination rates for the substance and/or the time it takes for the substance to undergo radioactive decay. Some insoluble substances may be retained for long periods in the lung following inhalation.

Radioiodine

The critical organ for radioiodine absorption is the thyroid gland, which uses iodine in the manufacture of the hormones which control the body's metabolism. Normally, the iodine in digested food is carried through the bloodstream, where some of it is absorbed by the thyroid. If radioiodines are inhaled, they move quickly from the lungs into the bloodstream, where the thyroid will absorb them, along with stable iodine.

One of the protective measures which can be taken if an individual has been exposed to radioiodines is to take potassium iodide (KI) or potassium iodate (KIO_3) pills. That will dilute the radioiodine in the blood so that less of it will be absorbed by the thyroid. The technique is called thyroid blocking. Isotopes of iodine not used by the thyroid are passed in the urine in two to three days (see **Provincial Emergency Plan,** page 95).

Tritium

Tritium, a weak beta emitter, is of no danger outside the body: its beta particles cannot penetrate the skin. But tritium is an isotope of hydrogen, and combines with oxygen to form water. Tritiated water poses a whole body danger because the body reacts with it as with water. It can be absorbed through the skin, inhaled in vapor and like all water, is eventually excreted in the urine.

Barium, Strontium and Radium

Barium and strontium are gamma and beta emitters. Radium emits both those radiations as well as alpha. These three radioisotopes behave chemically like calcium and migrate to the bones where they can irradiate them. Barium, radium and strontium isotopes are excreted very slowly, over many years and the radiation exposure may cause bone cancer.

Noble Gases

The radioactive noble gases are isotopes of helium, neon, argon, krypton, xenon and radon. Helium and neon decay in a second or less, and so are not of much concern. Noble gases are gamma and beta emitters, except for radon, which also emits alpha radiation. Since they are chemically inert, the noble gases are not metabolized. Noble gases can be inhaled, representing a minor radiation hazard while in the lungs. Externally, they cause radiation exposure to the skin and whole body.

Measuring The Effects

The biological damage caused by radiation exposure depends not only on the amount of radiation absorbed by the body, but also on the type of radiation, whether the exposure is internal or external, which part of the body receives the exposure and the time over which the exposure occurs.

Rad

When radiation interacts with tissue, it gives up energy to cause ionization. This energy is referred to as absorbed dose. The unit used to measure absorbed dose is the rad; it is an acronym for radiation absorbed dose. The rad measures the amount of energy absorbed per gram of tissue.

Rem

In the science of health physics, the rem is the unit used to measure the biological harm caused by radiation exposure.

A rem of one kind of radiation equals a rem of any other kind. In the Système Internationale, the rem is replaced by the sievert (see **Converting Between Radiological Units,** page 94).

To calculate the rem damage to the body of a given radiation exposure, one must first weight the rad according to the type of radiation involved, for different kinds of radiation deposit a different amount of energy per gram of tissue.

One rad of beta or gamma ray exposure equals one rem of exposure: they are very penetrating radiations and can cause exposure in all parts of the body.

Alpha and neutron radiations don't penetrate as far but produce denser ionization along their path through the tissue. One rad of fast neutron radiation results in 10 rem of exposure. One rad of alpha radiation results in 20 rem of exposure.

Particulate radiations do not have the penetration capability to pass through the body, so they don't damage all tissues. Ingesting or inhaling radioactive elements emitting alpha and beta particles is more dangerous than touching them. Externally, alpha articles cannot penetrate through the outer layer of skin, while the most energetic beta particles are able to penetrate two centimetres (three-quarters of an inch) of tissue and pose a hazard to the lens of the eye, and body surfaces (skin and extremities). But inside the body, alpha and beta particles can do significant damage because they deposit all their energy inside it.

Calculating the effects

Once the impact of the kind of radiation has been accounted for, and the exposure calculated in rem, the susceptibility of the part of the body exposed must be considered. The lungs, for example, are easily damaged while the kidneys are more resilient to fairly high levels of radiation.

The International Commission on Radiological Protection (ICRP) has established weighting factors for calculating the biological effect of any radioactive exposure:

0.12 red bone marrow
0.03 bone surface
0.03 thyroid
0.15 breast
0.12 lungs
0.25 ovaries and testes
0.30 remainder

1.00 whole body

An exposure of 4 rem to the thyroid is equal to 0.12 rem whole-body exposure (4 rem x 0.03, the thyroid weighting factor).

To calculate whole body exposures, the weighted exposures to the named body parts are added up with the remaining factor of 0.30 divided into five weights of 0.06 and assigned to each of the five organs or tissues receiving the highest rem exposures of the remaining tissues.

Exposure limits

The ICRP maximum exposure limits (see pages 23 and 25) are based on continued research of natural background exposures, accidental and medical exposures and studies of survivors of the atomic bombings in Japan. The limits have been revised over the years. Maximum exposure is defined as being maximum exposure which is not expected to cause any injury or effect that the individual and/or medical authorities would regard as being harmful to health.

Ionizing Radiation Exposures and Effects

0.002 rem (2 millirem)
- Average annual exposure in Ontario from nuclear weapons test fallout.
- Typical exposure from operating a video display terminal for a year.

0.005 rem (5 millirem)
- Exposure received flying from Toronto to Vancouver, because of the higher altitude, which provides less atmospheric shielding from cosmic radiation.
- The approximate exposure that a person might expect to receive from living at the boundary of a nuclear power station for a year.

0.02 rem (20 millirem)
- Average exposure from a chest X-ray.

0.1 rem (100 millirem)
- Exposure from a dental X-ray to the cheek.
- Averaged annual exposure for Ontarians from medical tests and X-rays.

0.220 rem (220 millirem)
- Average minimum radiation exposure received annually by people living at sea level. Called normal background radiation, it is from radon in building materials such as concrete and granite, cosmic rays and other sources. The probability of cancer from this exposure is two cases per 100,000 people.

0.5 rem (500 millirem)
- Maximum permissible whole-body exposure to members of public from Ontario Hydro nuclear plants.

0.7 rem (700 millirem)
- Actual average annual whole-body exposure to Ontario Hydro atomic radiation workers exposed to radiation.

5 rem
- Maximum permissible annual whole-body exposure for atomic radiation workers at Ontario Hydro.

10 rem
- If given instantaneously, would not cause obvious illness: might cause cancer five to 30 years later in one out of every 1,000 people exposed. (In Canada, cancer kills about 20 per cent of all people.)

15 rem
- Maximum permissable single-organ (i.e. lung, eye) annual exposure to most organs for Hydro atomic radiation workers.

30 rem
- Clinical effects of radiation exposure are only observable in instant exposures above 30 rem.
- Atomic radiation workers' maximum permissable annual exposure to skin, bone and thyroid gland.

75 rem
- Maximum permissible annual exposure to the extremities (all parts of hands, forearms, feet and ankles) of atomic radiation workers at Hydro.

90 rem
- Average exposure received by those who survived Hiroshima and Nagasaki.

100 rem
- If given instantaneously, might cause nausea. Might cause cancer five to 30 years later in one of every 100 people exposed to this amount.

150 rem
- Typical diagnostic exposure for a thyroid scan.

500-600 rem
- Standard whole body X-ray irradiation of leukemia patients to kill their bone marrow before they receive a bone marrow transplant.
- If given instantaneously, to a whole body in a non-medical setting, would cause nausea, vomiting, diarrhea in first hours followed by emaciation and damage to bone marrow, spleen and lymph nodes. Some deaths in the first few weeks, followed by possible death to 50 per cent of individuals if no medical treatment is provided.

4,000 rem
- Common exposure to Iodine-131 for thyroid cancer treatment.

6,000 rem
- Average exposure for treatment of a localized cancerous tumor. The radiation beam is concentrated on the growth.

Effects of Low-Level Radiation Exposure

At high radiation exposures, biological effects are readily observable. But the long-term consequences of low radiation exposure are difficult to prove conclusively. Since they can't be observed, an increasingly larger population would have to be studied as the level of exposure decreases.

For example, to find out if an exposure to an additional three millirem a year would increase the number of genetic defects, a population of 700 million would have to be observed for three generations.*

Because of the impossibility of this sort of study, the effects of low-level radiation exposure are calculated using linear theory: the likelihood of an effect occurring is directly (linearly) proportional to the exposure, with no threshold below which there will be no effect; the consequences of half as large an exposure will be half as severe.

Some scientists feel this method results in overstating the danger of low-level exposure since the body is able to repair minor cell damage as part of its regenerative process. Other scientists feel linear theory minimizes long-term exposure. Linear theory is, however, the international standard for calculating exposure effects.

Based on the linear theory, the following effects would be expected from exposure to one rem.

Cancer risk**

Cancer kills 21 per cent, or 2,100, of every 10,000 Canadians. If 10,000 people were each to receive an exposure of one rem, one additional fatal cancer due to the radiation exposure would be expected. For any one of those exposed, the risk of contracting a fatal cancer from the radiation would be 0.01 per cent, increasing the overall risk to 21.01 per cent per individual in a 10,000 population sample.

Genetic risk***

Approximately one person in 10 suffers from hereditary genetic defects leading to clinically detectable disease at some time in their life.

If 10,000 potential parents were exposed to one rem each, one additional hereditary defect would be expected among the first two generations of their children.

Risk to the unborn child

The natural occurrence of congenital malformations is about 50,000 cases per million children.

A recent study of children who were exposed before birth to radiation during the atomic bombings of Japan indicated an increased incidence of microcephalacy (mental retardation associated with smaller head size). The United Nations gives a risk estimate for microcephalacy of 1,000 cases in a million children receiving an average of one rem each of exposure while still in the womb.†

It is estimated that the same exposure would also increase the likelihood of childhood deaths from cancer: 580 cancer deaths per million children receiving one rem before birth.††

An average 600 cases of fatal cancer occur naturally per million children up to the age of 10.

* *Facts about low-level radiation,* International Atomic Energy Agency, World Health Organization, p. 1.

** From International Commission on Radiological Protection (ICRP) Publication 26, *Annals of the ICRP,* Vol. 1 No. 3, Pergamon Press, 1977.

*** Ibid.

† *Sources and Effects of Ionizing Radiation,* United Nations Scientific Community on the Effects of Atomic Radiation (UNSCEAR) Report, United Nations Publications, New York, 1977.

†† *The Effects on populations of Exposure to Low Levels of Ionizing Radiation,* Committee on the Biological Effects of Ionizing Radiation (BEIR) of the U.S. National Academy of Sciences, National Academy Press, Washington D.C., 1980.

Risk Analysis

Risk analysis has developed as a new discipline in the last 20 years. It establishes probable consequences of actions based on statistical extrapolations and so allows for comparison of dissimilar activities.

Risk analysis is an integral part of the design and licensing philosophy underpinning the nuclear power industry.

Probability of Risk Versus Perception of Risk

While risk analysis quantifies dangers, it cannot measure the dimension of an issue which is often the pivotal consideration in any action we undertake: our perception of risk.

A person smokes a cigarette then buys a lottery ticket. The odds the one action will lead to terminal lung cancer and the other to millionaire status are both about a million to one. Yet the odds feel different: the cancer can't result from just one cigarette; the ticket had a lucky number on it and somebody has to win . . .

An excellent and thorough treatment of the perception of risk ran in the *Washington Post,* May 21, 1986. By staff writer Don Colburn, "You Bet Your Life, Weighing the Risks in an Age of Uncertainty", can be accessed through Info Globe's Dow Jones News/Retrieval Service. Telephone 585-5250 for more information.

Some One In A Million Risks

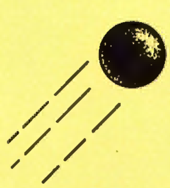
The following activities increase our chances of death by one in a million:

Activity	**Death By**
Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 litre of wine	Cirrhosis of the liver
Living with a cigarette smoker for 2 months	Cancer, heart disease
Spending one hour in a coal mine	Black lung disease
Spending three hours in a coal mine	Accident
Travelling six minutes by canoe	Accident
Travelling 16 km (10 miles) by bicycle	Accident
Travelling 48 km (30 miles) by car	Accident
Flying 1,600 km (1000 miles) by jet	Accident
Flying 9,600 km (6000 miles) by jet	Cancer from cosmic radiation
Living two days in New York or Boston	Air pollution
Living two months in Denver	Cancer from cosmic radiation
Living two months in an average brick building	Cancer from natural radioactivity
Eating 500 g (17.5 ounces) of peanut butter	Liver cancer from aflatoxin B (carcinogen produced by a mould which grows on peanuts)
Eating 100 charcoal broiled steaks	Cancer from benzopyrene (carcinogen found in hydrocarbons which can cause various cancers)
Living for 20 years near a polyvinyl chloride (plastics) plant	Cancer from vinyl chloride (1976 standard)
Living in the open at the boundary of a typical nuclear power plant for five years	Cancer from radiation
Living within eight km (five miles) of a nuclear reactor for 50 years	Cancer from radiation related to a major accident

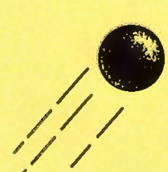
Reprinted with permission from R. Wilson, "Analyzing the Daily Risks of Life", pp. 41-46, *Technology Review,* February 1979.

Fission

Fission



Fission



Nuclear Fission in Uranium

A "free neutron"—one which has been ejected from an atom and is hurtling through a substance—will pass through most other atoms, or be absorbed by one of them.

Uranium-235 atoms, however, are more likely to split—fission—than absorb a bombarding neutron.

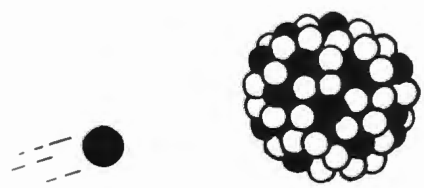
Fission—Play By Play

Nucleus is unstable

Uranium atoms have large nuclei with 92 protons. Since they are all positively charged, the protons repel each other and try to push apart but are bound in the nucleus by the strong nuclear force.

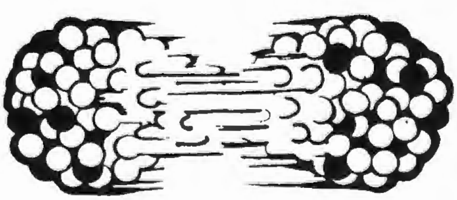
Neutron hits nucleus

More energy is added to the already energetic U-235 atom when a free neutron hits it and tries to fit inside the crowded nucleus. This new nucleus is now in a highly energized state and is extremely unstable.



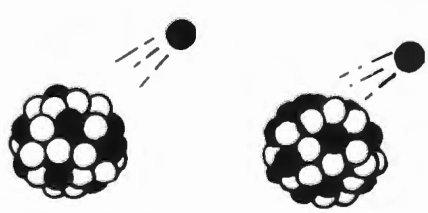
Nucleus splits

In an attempt to become more stable, the nucleus splits into two nearly equal parts, called *fission products* or *fission fragments.*



Energy released

Splitting releases much of the nucleus' energy, mostly as *heat,* but also as radiation, and ejects two or three free neutrons.

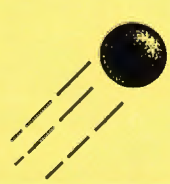


Harnessing The Atom to Generate Electricity

Except for fast breeder reactors (see page 71), all large-scale electricity-generating nuclear reactors are thermal neutron reactors. That means they use a moderator to slow down fast neutrons from their average ejection speed of 20,000 kilometres (12,400 miles) per second to "thermal velocity" (2,220 metres—7,300 feet—per second)—a speed at which they are likely to penetrate a nucleus and remain in it long enough to cause a fission reaction.

When a uranium atom splits, heat is released as well as various radiations. All thermal neutron reactors use the heat from fissioning uranium to boil water into steam. Steam turns the turbine-generator. The turbine-generator produces electricity.

Whatever the specifics of their design, these reactors all use uranium fuel, a moderator to slow down the free neutrons, a heat transport system to carry the heat out of the reactor core (either as steam or as another substance whose heat will be used to generate steam), and a control system to regulate the reactor.



Fuel

Uranium is the only naturally-occurring fission fuel for nuclear reactors.

Any sample of uranium contains three uranium isotopes, in these proportions:
- more than 99 per cent U-238;
- 0.7 per cent U-235;
- the rest U-234.

It is extremely difficult to separate the three isotopes.

It is only the U-235, the 0.7 per cent of any given quantity of uranium, which can be counted on to fission.

The abundant U-238 isotope will occasionally fission, but will usually just absorb the bombarding neutron into its large relatively stable nucleus.

Fuel Form

Almost all commercial reactors use a ceramic form of uranium, uranium dioxide. It is more stable and has a higher melting point than uranium metal. Whatever its composition, uranium fuel for nuclear reactors is usually housed in long thin tubes.

Fuel Manufacture

The rock in a uranium mine contains, on average, less than one per cent uranium. The recently-discovered ore deposits in Saskatchewan containing up to 40 per cent uranium are a significant exception.

At a mill, generally near the mine, the ore is crushed. When liquid chemicals are added, the uranium dissolves and can be poured off, leaving the solid wastes. It is then chemically extracted from the liquid and dried. This yellowcake, as it is called, is a powder containing 60 to 70 per cent uranium oxide. It is packed in drums and shipped to a refinery where further chemical purification turns it into pure uranium trioxide.

To produce the natural uranium fuel used in CANDUs, the uranium trioxide is dissolved in nitric acid, mixed with ammonia and heated with hydrogen. The resulting brown powder, uranium dioxide, is pressed into cylindrical pellets and heated to 1,600-1,700°C (2,900-3,100°F), creating a ceramic. At this point, the fuel is ready to be assembled into bundles to be used in CANDU reactors. However, before it can be used in reactors other than CANDU, the Uranium-235 content must be upgraded, or enriched, from the naturally-occurring 0.7 per cent to between two and four per cent.

Fuel Enrichment

The two principal enrichment methods exploit the fact that U-235 is lighter than U-238. Both require that the uranium oxide first be converted to uranium hexafloride gas (UF_6). In the gaseous diffusion method, UF_6 is forced through a porous metal. The lighter atoms move faster and pass more readily through the barrier. In the centrifuge enrichment method, U-235 atoms collect at the axis when UF_6 is spun in a centrifuge.

While still largely experimental, laser enrichment looks like a promising technology. Since U-235 and U-238 absorb different wavelengths of light, different frequencies of laser are used to excite and separate the isotopes.

After enrichment, the uranium is pressed and heated, turning it into a ceramic.

Properties Of Uranium

Before going in a reactor, uranium fuel is only slightly radioactive, it can be held in the bare hand. That is because the isotopes of uranium have such long half-lives that they are not emitting much radiation. U-238 has a half-life of 4.5 billion years; U-235, of 713 million years; U-234, of 248,000 years.

In fact, because of its high density (1.7 times heavier than lead) and low radiation, depleted uranium (the part that is left after enrichment has removed the U-235) is used as a counterweight in airplanes. It is often used as a shielding for other radioactive material. One centimetre (one quarter of an inch) of uranium stops radiation as well as 12 centimetres (five inches) of concrete.

Fuel Power

A single CANDU fuel bundle remains in the reactor for about 15 months. In that time, it produces enough heat to generate more than 1,000 megawatt-hours of electricity, enough to supply the needs of 100 households for one year. It would take 400 tonnes of coal to supply enough heat to generate that amount of electricity.

While all of the nuclear waste is locked in one fuel bundle, burning 400 tonnes of coal produces 27.2 tonnes of flyash, 6.8 tonnes of bottom ash, 1,022 tonnes of carbon dioxide, 20 tonnes of sulphur dioxide and 4.3 tonnes of nitrogen oxide.

Moderator

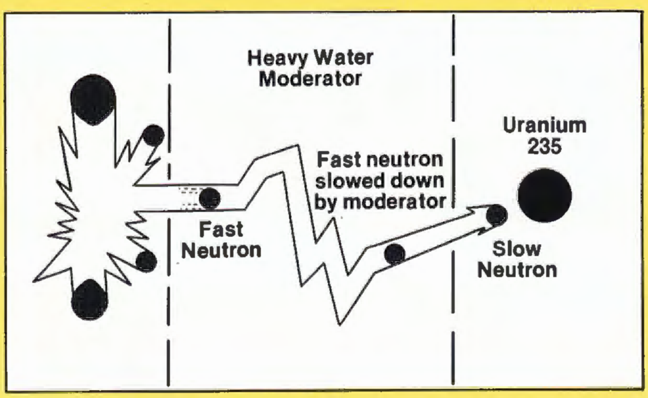
The free neutrons emitted from the random natural fissions which occur in Uranium-235 travel so quickly that they are more likely to pass through adjacent atoms than to penetrate nuclei and stay long enough for them to cause a fission reaction.

To increase the odds that the free neutrons will strike and split other nuclei, and so create the heat needed for electricity generation, the neutrons must be slowed down, or moderated, to a speed of about 2,200 metres (7,300 feet) per second. This is called thermal velocity and gives rise to the name of the reactor design.

In thermal neutron reactors, the uranium fuel is spaced throughout the reactor and surrounded by a moderator. This design maximizes the likelihood that fast neutrons will travel away from the uranium pellet which contains them, encounter the resistance of the moderator, slow down, penetrate another pellet of uranium and cause a fission reaction.

The condition for a self-sustaining nuclear reaction is that at least one neutron from a fissioning nucleus must cause fission in another nucleus.

The most frequently used moderators are ordinary water (light water), deuterium (heavy water) and graphite.



How Heavy Water is Made

Heavy water is one of the most efficient moderators and enables the CANDU to run on natural uranium. The CANDU design also uses heavy water in the heat transport system, discussed on the next page.

Deuterium oxide is called heavy water because it is heavier than normal water by about 10 per cent. Heavy water occurs naturally in minute quantities in ordinary water—about one part heavy water per 7,000 parts water.

Ontario Hydro extracts heavy water from lake water at a plant located at the Bruce Nuclear Power Development, near Kincardine.

To produce one megagram (2,200 pounds) of heavy water, 340,000 megagrams (340,000 tonnes) of lake water must be circulated through the plant. After passing through the system, water is returned to the lake, depleted of 19 per cent of its heavy water molecules.

Heavy water is concentrated using two processes. First, a chemical enrichment process using hydrogen sulphide gas (H_2S) increases the concentration of heavy water in the water to 30 per cent.

The second step is a distillation process which brings the water to 99.75 per cent pure reactor grade heavy water.

The Bruce Heavy Water Plant produces 800 megagrams (800 tonnes) of heavy water a year. That is enough for one Bruce or Darlington reactor. Pickering units require 600 megagrams (600 tonnes). Once in service, each reactor only needs to be "topped up" with about five megagrams (five tonnes) a year to replace the water which leaks from the reactor and is collected in sumps or the vapor dryer. The collected heavy water is no longer pure and must be upgraded before being returned to the system. Each generating station has a small heavy water upgrading facility.

Heat Transfer System/Coolant System

A fission reaction creates heat in the uranium fuel. This heat is transferred from the fuel and used to boil water into the steam needed to turn a turbine generator. Since the heat transfer system removes heat from the fuel, and so stops it from overheating, it is also called the coolant system. The heat is transferred through either a direct or indirect cycle. The major reactor designs in use are listed on the next page.

Direct Cycle

Water used to cool the fuel is allowed to boil in the reactor core and produce steam to drive the turbine directly.

Indirect Cycle

A heat transfer substance—water or gas—circulates over the fuel, picks up heat then passes through the steam generator where it causes ordinary water (in a separate circuit) to boil. The resulting steam is directed to the turbine.

Control System

The number of free neutrons passing through the fuel at any one time is referred to as the "neutron population". That population grows or declines, depending on the number of "births"—fissions—one generation of neutrons is able to cause before losing energy and "dying" inside the fuel.

Not all neutrons released through fission cause fission: some are absorbed by the structural materials in the reactor; some escape from the reactor into the reactor building; some are absorbed by materials deliberately inserted in the core to control power.

The more fissions that occur, the more heat is produced in the fuel and the higher the reactor power or thermal power that results.*

To keep the power level of a reactor constant, the same number of neutrons must be "born" as the number that "die". This stable state is called a critical state. If more neutrons die than are born, power will fall; if more are born than die, the power will rise.

During the normal operation of a reactor, the operator must be able to safely manoeuvre the reactor between different power levels. If the power is higher than desired, rods of neutron-absorbing material suspended above the reactor are lowered into the core. Many of the free neutrons travelling through the moderator are absorbed by the control rods and so the number making contact with U-235 atoms is reduced, the number of fissions declines and the reactor power drops.

* Thermal power is written th. Generally, CANDU units are about 30 per cent efficient at converting thermal power to electrical power (e). Therefore, if the reactor produces 1000 MWth, the turbine generator should be able to produce 300 MWe. The output of Ontario Hydro units is normally given in megawatts electric. It is worth remembering, however, that the actual power in the reactor is three times higher.

Major Commercial Reactor Designs In Use

Reactor Type	Fuel	Moderator	Heat Transfer System (Coolant)	Reactors—Number Operating (number under design and construction)*			Totals
PWR pressurized water reactor	enriched uranium	the same pressurized light water system moderates the reaction and transfers heat to the boilers		Belgium 7 Brazil 1(2) Bulgaria 5(3) China (3) Cuba (2) Czechoslovakia 8(7) Finland 2 France 44(12)	E. Germany 5(6) W. Germany 11(6) Hungary 4(2) Italy 1(2) Japan 16(7) Netherlands 1 Phillipines (1) Poland (6) Romania (1)	South Africa 2 South Korea 6(4) Spain 5(7) Sweden 3 Switzerland 3 Taiwan 2 U.K. (1) U.S.A. 67(17) U.S.S.R. 26(18) Yugoslavia 1	220 (107)
BWR boiling water reactor	enriched uranium	the same light water system moderates the reaction, is heated to boiling in the core and supplies steam directly to the turbine		Finland 2 W. Germany 7 India 2 Italy 1(2)	Japan 18(7) Mexico (2) Netherlands 1 Spain 2(2) Sweden 9	Switzerland 2 Taiwan 4 U.S.A. 33(7) U.S.S.R. 1	82 (20)
GCR gas cooled reactor	natural uranium	graphite	carbon dioxide gas	France 4 Italy 1 Japan 1	Spain 1 U.K. 26		33
CANDU Canada Deuterium Uranium	natural uranium	heavy water	pressurized heavy water	Argentina 1 Canada 18(4) India 2	Romania (5) South Korea 1		22 (9)
LGR (RBMK) cooled graphite moderated	enriched uranium	graphite	light water boils in core	U.S.S.R. 23(5)			23 (5)
AGR advanced gas cooled	enriched uranium	graphite	carbon dioxide gas	U.K. 10(4)			10 (4)
LMFBR liquid metal fast breeder	enriched uranium	none	liquid sodium metal	France 1(1) W. Germany (1) Japan (1)	U.K. 1 U.S.S.R. 2		4 (3)
						TOTALS	394 (148)

This table has been compiled from data in *Nuclear News*, February 1988, and is accurate as of December, 1987.

* As of December 1, 1987, there are 564 nuclear reactors of over 30 megawatts operating or being designed and built in the world. They represent a net electrical production of 437,170 MW. The 22 reactors not included in this chart use designs which are either unusual or not intended primarily for electricity generation.

Fast Breeder Reactors

The fast breeder reactor, as the name suggests, uses fast (i.e. un-moderated) neutrons to sustain the fission reaction and, through interaction with natural uranium, to "breed" fissile plutonium.

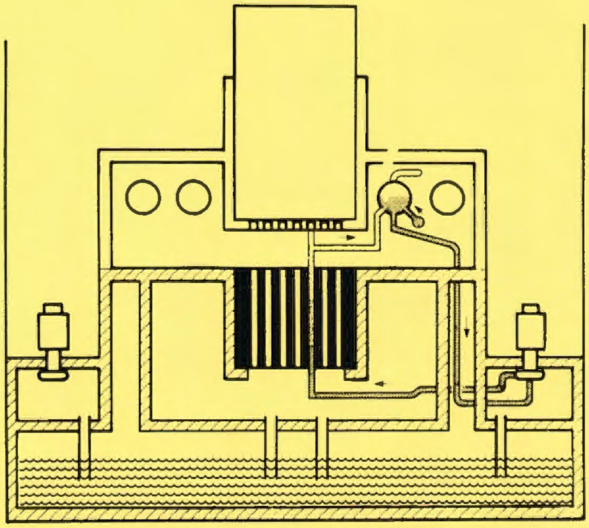
Essentially the fast breeder consists of a core made up of uranium, typically enriched to 10 to 20 per cent fissile material (either Uranium-235 or Plutonium-239). Surrounding this is an arrangement of natural uranium fuel known as the "breeding blanket". The heat transfer medium (coolant) most commonly used is liquid sodium metal or liquid sodium-potassium. For this reason, this reactor type is known as the Liquid Metal Fast Breeder Reactor (LMFBR). The central part of the core generates heat, as in the normal thermal reactor, and this heat is transferred to boilers (usually via two circuits) by the heat transfer medium. The primary coolant circuit transfers heat to a secondary (liquid metal) circuit which in turn transfers heat to ordinary water in the boilers. This approach is adopted to preclude the possibility of the radioactive liquid metal ever mixing with water.

At the same time as heat is being generated in the core, spare neutrons from the core interact with the U-238 in the breeding blanket. When a U-238 nucleus absorbs a neutron it ultimately decays to Pu-239. The plutonium atoms also fission. (This also occurs in the CANDU reactor, where more than one third of the energy produced comes from the fissioning of plutonium.)

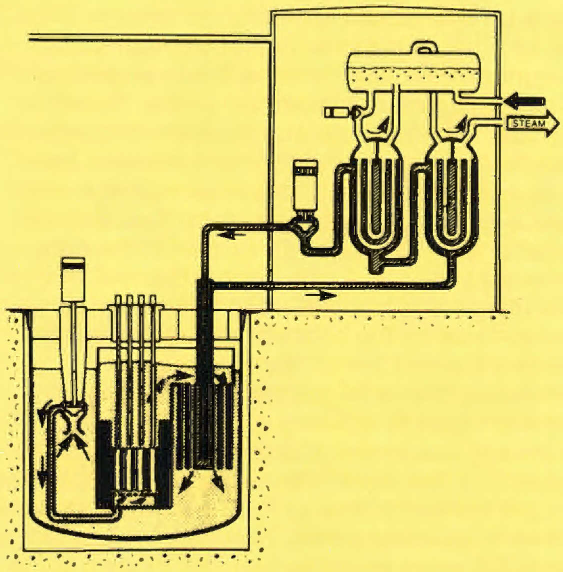
This process takes place in the core as well, and some of the plutonium so produced is subsequently consumed. But plutonium is produced at a faster rate than the total fissile material in the core is consumed, hence, the breeder characterization. At regular intervals, a proportion of the breeder blanket uranium rods are removed from the reactor and the plutonium is extracted to be fabricated into fresh fuel.

The fast breeder reactor is a particularly attractive concept to those countries with no indigenous uranium resources. Britain, France and the Soviet Union all have fast breeder reactors in operation.

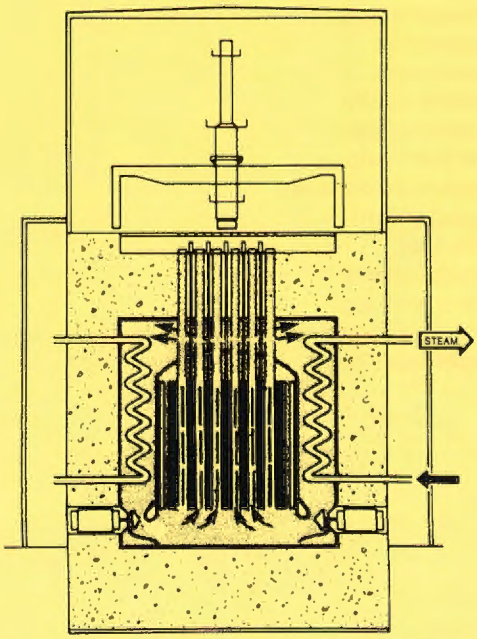
Major Commercial Reactor Designs In Use



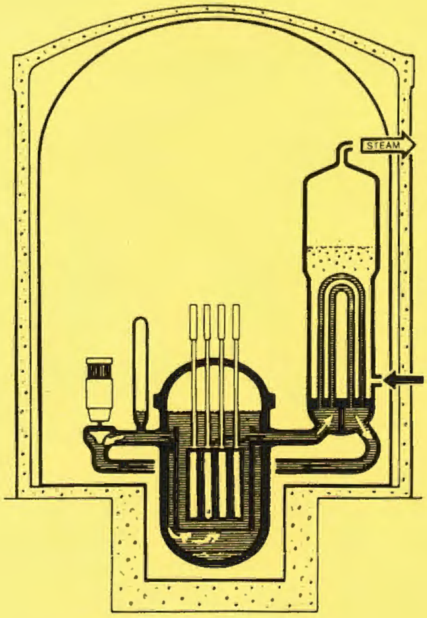
LGR (RMBK—1000)



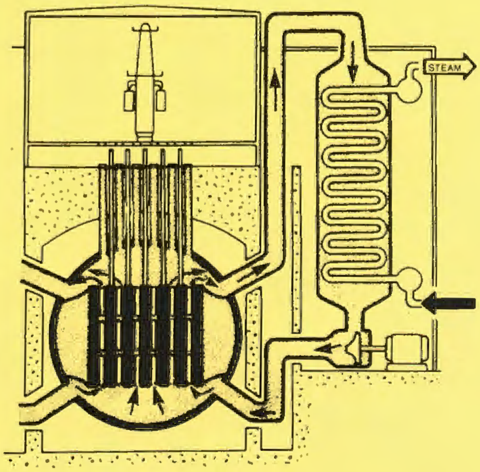
Liquid Metal Fast Breeder Reactor—LMFBR



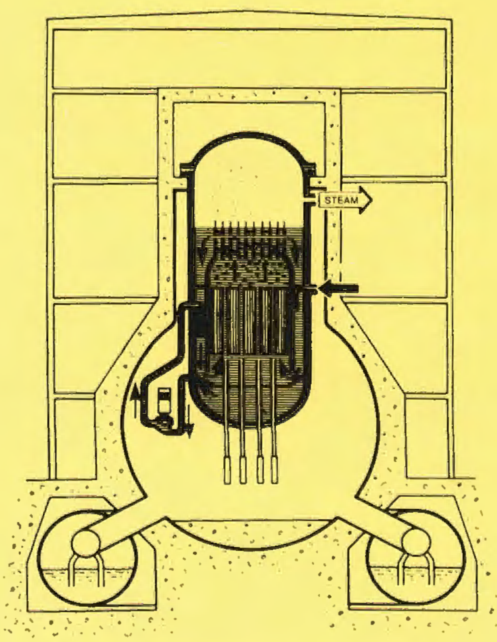
Advanced Gas-Cooled Reactor—AGR



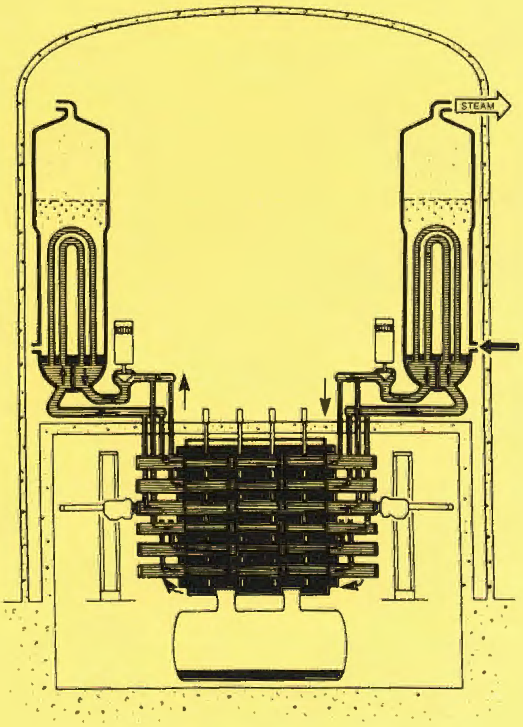
Pressurized Water Reactor—PWR



Gas Cooled Reactor—GCR



Boiling Water Reactor—BWR



CANDU Reactor

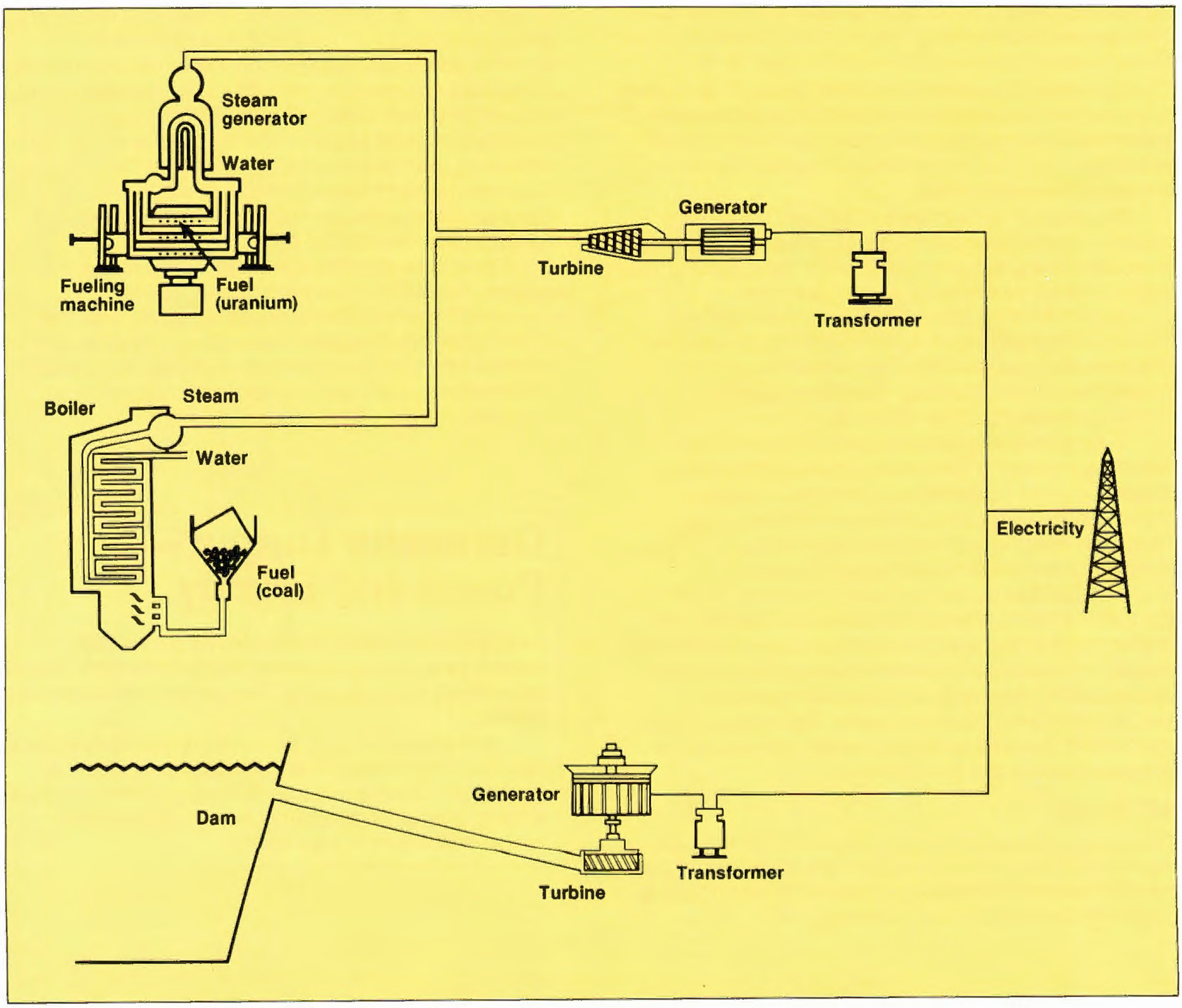
Turning The Turbine

In both nuclear and fossil-fired generating stations, the fuel serves the same function: it is a source of heat, used to boil water and produce high-pressure steam. From that point on, the same technology is used to generate electricity in both types of plants.

A turbine resembles a paddle wheel. Jets of high-pressure steam hit the paddles, or blades, turn the wheel and thus the shaft. The shaft is connected to the rotor of the generator, where mechanical energy is converted into electrical energy.

For safety and ease of operation in a nuclear plant, the nuclear reactor is located inside a reinforced containment structure and separated from the turbine generator and other conventional systems. (When you hear that a generator at a nuclear station is down for repairs, there is no direct connection with the nuclear reactor part of the station.)

At a hydro-electric plant, the principle of electricity generation is the same, but falling water is used directly to drive the turbine.



Electromagnetic Force and Electricity Generation

Atomic particles exhibit some basic electrical properties:

- Particles with opposite electric charges are attracted to each other; particles with the same charge are repelled by each other.
- Electrons are small, negatively-charged particles which spin around a nucleus, normally containing an equal number of much bigger positively-charged particles called protons, as well as some particles with no electric charge, neutrons.
- Metals in general, and copper in particular, have a high concentration of free electrons—electrons which are held only loosely to their orbit around the nucleus containing the protons. These free electrons are easily pushed out of their orbit.

Electricity is a manufactured product. To make it, we exploit the electro-magnetic characteristics of electrons moving freely in a good conductor, such as copper, and the force exerted on them by a changing magnetic field.

If a loop of copper wire is passed between a negative and a positive magnetic pole, the free electrons are disrupted from their loose orbit around the nuclei and move toward the positive pole.

But if the wire is kept between the magnetic poles for a length of time, the electrons eventually stop moving and return to their usual weak orbit. To keep electrons moving, they have to keep crossing magnetic lines of force.

A large-scale alternating current generator contains a rotating electro-magnet called a rotor. It spins—up to 3,600 times a minute—inside a stationary cylindrical container called a stator. There are longitudinal slots along the inside of the stator which contain windings of copper wire.

The turbine is connected to the rotor, so when the turbine spins, the rotor also spins. The billions of electrons in the copper windings mounted on the stator continuously encounter alternately positive and negative magnetic fields which keep the electrons moving back and forth. The windings are connected to wires which carry this current out of the generator to the transformer.

AC Power

The power generated in this way is called alternating current (AC) power because the direction of the electric current reverses, or alternates, each time a different magnetic pole is passed.

Frequency

A cycle of alternating current occurs when the electrons have moved as much as they can in one, then the other direction. The frequency of the cycle is expressed in Hertz (Hz). Ontario Hydro generates 60 Hz, or 60 cycle power: there are 60 complete back and forth cycles of electron movement every second.

Originally, the area from Toronto to Sarnia and Windsor, the major power consuming part of the province, used 25 Hz electricity. In 1948, the Power Corporation Act was amended to pave the way for conversion of 25 Hz customers to 60 Hz. Frequency conversion began in 1949 and was completed in about 10 years, although small industrial pockets of 25 Hz exist to this day—notably, the Hamilton steel mills which draw about 40 MW. Some generating stations continue to generate at 25 Hz to serve the remaining customers who decided that the expense of converting was not worth the advantages (the Act stipulated that existing facilities could remain but that new plants must be 60 Hz).

Ontario Hydro changed frequency for several reasons: for utilities and the public, 60-Hz equipment is smaller and cheaper; 60-Hz was the North American standard and with expansion and interconnection envisioned, it made sense to have the Ontario system compatible with neighboring systems.

Generator Output—Power and Energy

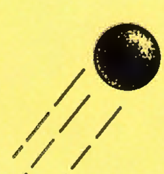
At any one moment, an electricity generator produces a given amount of electric current, usually expressed in megawatts. This is the unit's electrical power.

A megawatt-hour, however, is an expression of the electrical energy the generator produces. A generator which produces 500 megawatts of power, after one hour of operation, has produced 500 megawatt-hours of electricity.

Electricity

Electricity

Electricity



Current and Voltage

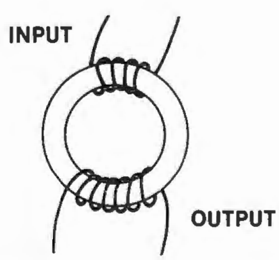
The difference between current and voltage can be explained by an analogy of the flow of water through a pipe.

If the copper wire is the pipe, the electric current is the water. Water pressure is like voltage, the force with which the water moves. Pounds per square inch (pascals in the metric system) is the measure of water pressure; volts is the measure of electric pressure.

Transformers

Large generators usually produce electricity at about 20,000 volts, far too low to be efficiently transmitted. So the power is "stepped up" by passing it through a transformer.

A simplified transformer would look like this:



The input wire is the copper wire from the generator, carrying 20,000-volt AC electricity. It induces a magnetic flow around the iron ring. Each time the current in the wire alternates—changes direction—the magnetic flow in the ring changes. Each change induces an electric current in the output copper wire. The voltage in the output wire is determined by the number of turns of output wire around the conductor ring: to increase the voltage, the output wire is wrapped around more times. In a transformer designed to reduce, or "step down", the voltage, the output has fewer turns than the input. A transformer does not affect the amount of electric energy, only its voltage.

Transmission and Distribution

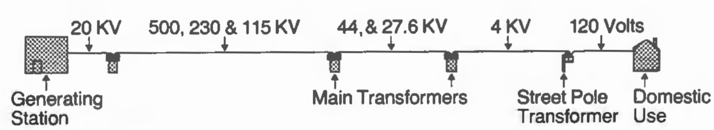
Before it leaves Hydro's generating stations, electricity is stepped up to 115, 230 or 500 kilovolts (a kilovolt or kv is 1,000 volts). Transmitting electricity at higher voltages ensures that a minimum of electricity will be lost along the way as heat.

The transmission system consists of 15,546 km (9,660 miles) of high voltage (115 and 230 kv) and extra-high voltage (500 kv) lines, as well as towers and transformer stations. This is known as the bulk-electricity system.

At transformer stations the voltage is reduced to 27.6 or 44kv. In Ontario, there are about 100,000 km (62,138 miles) of lines strung on more than one million poles, which carry electricity at less than 50 kv. This network is known as the distribution system.

As the electricity gets closer to where it will be used, it is stepped down again, at distribution stations, to 8.32 or 12.5 kv. By the time the electricity reaches street pole transformers, it has been reduced to 4 kv. There, it is stepped down once more to 120 volts, the voltage at which it serves most homes.

In urban areas of Ontario, more than 300 local municipal utilities buy power from Ontario Hydro then step it down and distribute it on their own equipment.



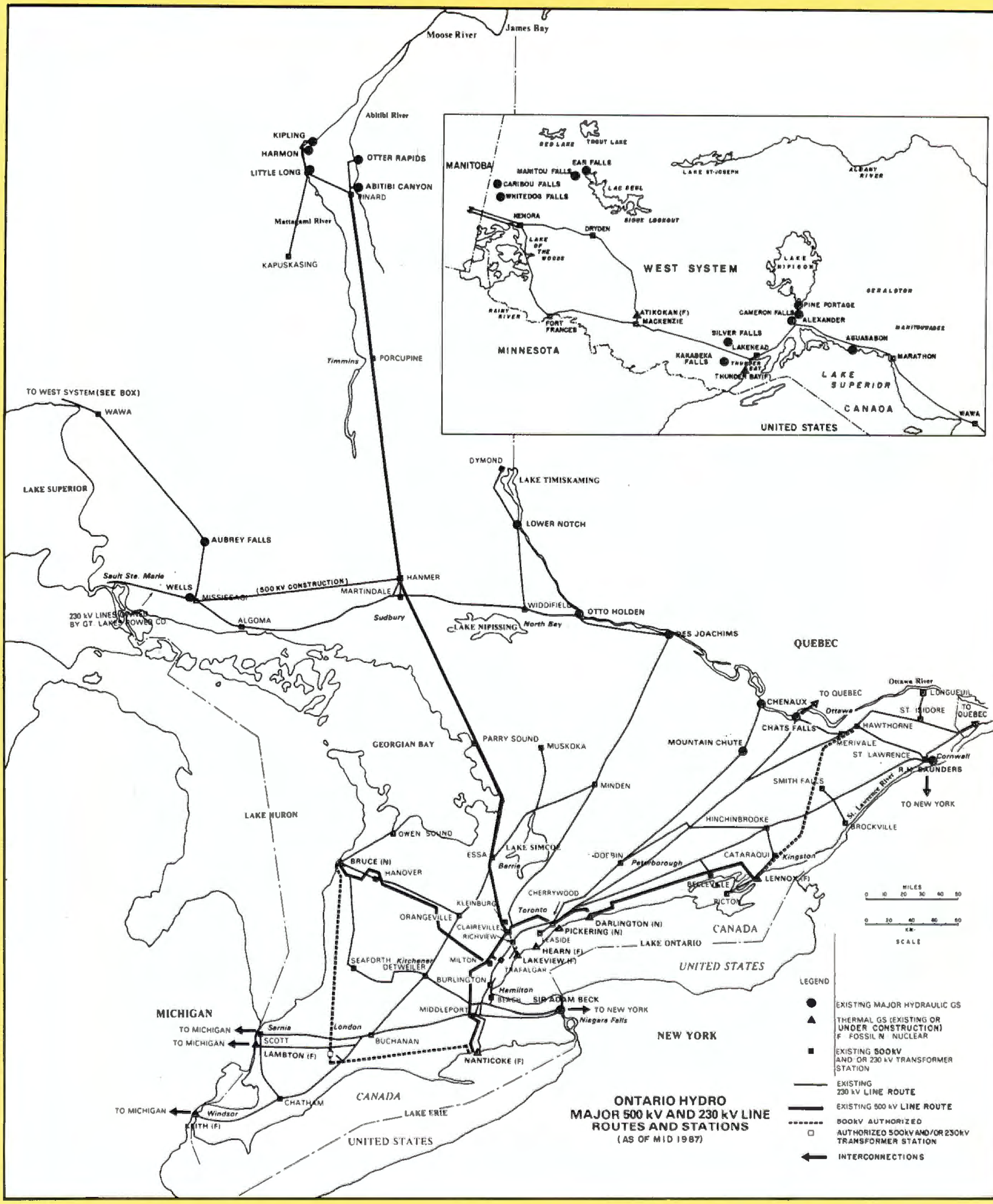
Plugging in The Plug

Just as water at the appropriate pressure waits in the pipes in your house until you turn on the tap, electricity waits in the wires in the walls behind the socket until you flip the switch or plug in the plug.

Electrons follow a metallic path. They travel through the wires in the house until they reach the wall outlet, then stop—there is no more path. When inserted into the socket, the prongs of a plug act as a bridge, conducting the electric current through the wire of the appliance.

If the switch on the appliance is turned off, an insulator—air—blocks the path of the current. Once the switch is in the on position, a metal bridge is formed, allowing the current to flow to where it is converted into another energy form. Flowing through the filament in a lamp, for instance, electric energy becomes light and heat energy. Through a television set, it converts electromagnetic waves of sound and light to electrical signals and retransmits them to the viewer.

Major Ontario Hydro Generating Stations and Transmission Routes



System Control

Aside from small generators in remote communities, none of Ontario Hydro's generating stations supplies electricity to a specific place. Electricity from all generating stations feeds into the transmission system, called a power grid, and flows to where it is needed.

The bulk electricity system comprises all the equipment involved in the high voltage transmission of electricity. At Ontario Hydro's System Control Centre, two Univac master computers process critical data from each of the province's 110 major generating stations, transformer stations and switching stations every two seconds. System control operators are in constant touch with essential electrical equipment in the province, ensuring that it is working properly.

Since electricity cannot be stored, the operators are constantly monitoring the province's electricity consumption and directing the generating stations to increase or decrease their electricity production to match the need.

Ontario Hydro's power grid is interconnected to the networks in Manitoba, part of Quebec, and the states of New York, Michigan and Minnesota. Through these interconnections, utilities buy and sell power to maintain electrical service when they cannot generate enough power for their own needs.

Surplus capacity is also bought and sold by operators in different control centres, if it is economic to do so. For example, it can be cheaper on a day-to-day basis for Ontario Hydro to buy Hydro Quebec's surplus hydro-electric power than to run a coal-fired plant here in Ontario. Similarly, it can be economical for U.S. utilities to buy nuclear or coal-fired electricity from Ontario Hydro to replace their oil-fired generation. Ontario Hydro makes a profit on electricity sales, $196 million in 1987.

Since the utilities Ontario Hydro has interconnections with are also connected to other jurisdictions, emergency power sales among utilities in the United States can increase our sales to New York, as everyone sells to their southern neighbor. This occurred, for instance, on May 17, 1985, when extensive forest fires destroyed parts of Florida Light and Power Company's transmission network.

In addition, we can "wheel" power for other utilities through our system, for a fee. If Michigan wants to sell power to New York, for example, they may send it across Ontario Hydro transmission lines.

Background and Statistics

Nuclear Development

Chronology

1928

- International Commission on Radiological Protection (ICRP) was established to provide basic recommendations on radiation protection. Headquartered in London, England, it still helps set international safety standards based on the best new research.

1938

- Uranium fission demonstrated in Berlin by Otto Hahn and Fritz Strassman.

1939

- French researchers realize fission could be used to generate electricity.

1940

- First Canadian experimental work with fission begins.
- Britain and U.S. realize that fission could be used to make bombs. Electricity reactor research is put on hold because of tremendous concern that Germany will develop a bomb before them. The Allies goal is to find a way to produce plutonium, using a reactor moderated by either heavy water or graphite.

1942

- Scientists from Cambridge—including Europeans who fled to England during the war—come to the new Montreal Laboratory at McGill University. They bring 200 kilograms (440 pounds) of heavy water, the world's store, which was smuggled out of Norway and France.
- Uranium, an unwanted byproduct of the Eldorado radium refinery at Port Hope, is suddenly a very valuable commodity. Eldorado is the only refinery in North America.
- The first man-made self-sustaining nuclear reaction occurs at a uranium and graphite "pile" designed by Enrico Fermi in Chicago. Graphite was used because of the limited supply of heavy water (the U.S. is building plants).

1943

- The United States, Great Britain and Canada agree to co-operate on fission research. But the American program, already far advanced at this point, needs little help.

1944

- August 19, the Canadian government decides to build a $25-million research facility on the Ottawa River. It is built by Defence Industries Limited, a wartime Crown corporation whose key employees had been drawn from Canadian Industries Limited (CIL), Canada's largest chemical manufacturer.
- Heavy water becomes available in quantity for the American nuclear program from plants in West Virginia, Indiana, Alabama, and Trail, British Columbia.

1945

- September 15, at Chalk River, Ontario, the Zero Energy Experimental Pile (ZEEP), the first reactor in the world outside the United States, goes critical. Moderated with heavy water, it is not intended to produce power (only a nominal one watt). ZEEP cost $200,000.

1946

- The Atomic Energy Control Act leads to the establishment of the Atomic Energy Control Board.

1947

- July 22, the National Research X-perimental reactor (NRX) starts up at Chalk River. The $10 million heavy water moderated reactor originally produces 20 megawatts of thermal power and is used as a research tool for all aspects of nuclear science and also for isotope production.

1949

- Ontario Hydro considers the potential of reactors for electricity generation.
- The first isotopes made in NRX are sold to chemical research labs.
- Design begins on another research reactor at the Chalk River site, the National Research Universal (NRU).

1951

- On October 27, at London Ontario's Victoria Hospital, the world's first Cobalt-60 therapy is given to a cancer patient.

1952

- April 1, a Crown corporation, Atomic Energy of Canada Limited (AECL) is created to develop nuclear technology.
- December 12, "Black Friday", a serious accident occurs at the NRX reactor. Because of two operator mistakes, the shutdown rods are disengaged. They leave the core, the fuel overheats, melts, releases significant radioactivity to the air. The reactor is brought under control by spilling some of the moderator to lower the number of fissions. Cleanup is extensive, involving Canadian and American servicemen (including former U.S. President Jimmy Carter). The calandria and the radioactive water from the building's basement are stored on site. Fourteen months later, NRX starts up again.

1953

- Ontario Hydro and AECL launch a feasibility study for a Nuclear Power Demonstration Project (NPD).

1954

- Ontario Hydro and AECL discuss the possibility of a larger, prototype reactor (Douglas Point).

1957

- On November 3, the National Research Universal (NRU) research reactor is started up. Built at a cost of $57 million, the reactor produces 200-megawatts of thermal power. It will produce radioisotopes and be used to study the transfer of heat for application in future electricity-generating reactors.
- The International Atomic Energy Agency (IAEA) is established. An agency of the United Nations, it sets standards for radiation safety and inspects nuclear facilities to ensure that no nuclear material is diverted to non-peaceful purposes.
- The design for a power reactor begun in 1953 by Hydro, AECL and Canadian General Electric is abandoned, in favor of a new one, NPD-2, which will have horizontal pressure tubes.

1958

- May 24, extensive contamination occurs at NRU when a damaged uranium rod being removed breaks, falls on the floor and catches fire. Canadian servicemen help with the cleanup. The reactor restarts in August.
- AECL establishes a Toronto office to work on the design of Douglas Point, a 200-megawatt CANDU, for Ontario Hydro.
- Pool Test Reactor (PTR) starts up at Chalk River. The 10-watt unit was designed by Canadair of Montreal to test reactivity and neutron-absorption in different substances.

1959

- Land is obtained at Douglas Point, on the Bruce Peninsula.

1960

- Construction starts on the $81.5-million Douglas Point reactor.
- September 7, the Zero Energy Deuterium (ZED-2) reactor starts up at Chalk River. CANDU rod configurations are tested in ZED-2.
- The Canadian Nuclear Association is established to promote the peaceful uses of nuclear energy.

1962

- On June 4, for the first time in Canada, electricity from a nuclear reactor is fed into the Ontario electrical grid. The 25-megawatt NPD reactor, near Rolphton, is in operation. It is a co-operative venture of AECL, Ontario Hydro and Canadian General Electric and cost $34.5 million. NPD is the first Canadian reactor to use uranium dioxide fuel in ceramic form instead of metal, and short fuel bundles instead of long rods (all have since).

1964

- On August 20, plans are announced for Canada's first large-scale nuclear station in Pickering Township. Two 540-megawatt reactors are designed for Ontario Hydro by AECL. Under the Nuclear Payback Agreement, AECL, Ontario Hydro and the Ontario government share both the capital costs and the revenues from the sale of the reactors' electricity.

1965

- AECL and Hydro-Quebec announce the construction of Gentilly 1, a 250-megawatt prototype boiling water CANDU located outside Trois Rivières, Quebec. AECL builds and sells power to Hydro-Quebec.

1966

- Douglas Point, Canada's first full-scale nuclear generating station achieves its first chain reaction. Ontario Hydro owns the conventional side of the station, AECL, the nuclear.
- Construction starts on Gentilly 1.

1967

- Douglas Point produces its first electric power.
- Ontario Hydro announces that it will double Pickering to four units.

1968

- Plans are announced for a nuclear station on the Bruce Peninsula, consisting of four 800-megawatt units. A heavy water plant is to be built on the site.
- Canada signs the Nuclear Non-Proliferation Treaty.

1970

- The Nuclear Liability Act is passed (it is discussed under Key Financial Issues).
- Gentilly 1 goes into service.

1971

- Pickering 1 comes into service July 29; Pickering 2 December 30.

1972

- Pickering 3 comes into service June 1.

1973

- Pickering 4 comes into service June 17.
- AECL heavy water plant at Douglas Point (the A plant) starts up in April. Ontario Hydro buys it in July.
- Construction of Gentilly 2, a 600-megawatt CANDU, is announced by AECL and Hydro-Quebec. It will be designed by AECL for the utility.

1974

- Power Corporation Act is passed.
- Construction starts on a four-unit B station at Pickering. There are also plans for two heavy water plants at the site, later cancelled (1976 and 1979).
- Construction starts on Gentilly 2.
- AECL and New Brunswick Power announce the construction of a 600-megawatt CANDU to be built by AECL at Pt. Lepreau.

1975

- Bruce B approved.
- Construction starts on Pt. Lepreau.
- Royal Commission on Electric Power Planning is appointed with Dr. Arthur Porter as chairman. It will sit until 1981, examining many issues, among them, planning and nuclear power, which it concludes is "acceptably safe".

Chronology

1977

- Approval given for construction of four 900-megawatt reactors in Darlington Township.
- The Bruce A reactors 1 and 2 are declared in service, both on September 1.

1978

- On February 1, Bruce 3 is in service.
- Provincial and federal governments announce plans for a joint program to research nuclear waste disposal.
- Construction starts on Darlington.
- Select Committee of the Legislature on Hydro Affairs is appointed. Sitting until 1981, it will examine a wide range of topics, including uranium contracts, Bruce heavy water plants, electricity demand, reactor safety, nuclear fuel management and system expansion. It also found Hydro's operations to be acceptably safe.

1979

- Bruce 4 in service January 18.

1981

- For the first time, nuclear stations in Ontario produce more electricity than either coal-fired or hydro-electric stations.

1982

- Canadian Fusion Fuels Technology Project is established. Ontario Hydro is the project manager and supplies 25 per cent of the funding. The Ontario government supplies another 25 per cent and the National Research Council funds the rest. The budget for the first five years is $16.5 million and for the second five, $22 million. Funding goes to fusion research projects run by universities, utilities and private industries.

1983

- Pickering 5 is in service, May 10.
- August 1, a pressure tube in Pickering unit 2 suddenly ruptures, spilling tonnes of radioactive heavy water into the reactor building. There is no release of radiation to the environment and the reactor is shut down before the situation becomes critical enough for the safety systems to operate. Inspection of several pressure tubes reveals that the Zircaloy-2 alloy that they were made from had blistered and cracked. This alloy was used only in the first two Pickering reactors. The first unit is shut down as well and Hydro assesses whether to replace all pressure tubes in both units.
- Gentilly 1 closed; the boiling water CANDU design did not meet the high standards of reliability and safety attained by the heavy water CANDU.
- Pt. Lepreau goes into service in January.
- Gentilly 2 goes into service in October.
- Heavy Water Plant B at the Bruce site goes into service in June and is bought by Ontario Hydro from AECL in July.

1984

- Pickering 6 is in service February 1.
- Bruce 6 is in service September 14.
- Douglas Point is shut down, because it has fulfilled its function as a prototype and is no longer needed. Heavy Water Plant A on site is also closed.
- Decision is made to retube Pickering 1 and 2.

1985

- Pickering 7 is in service January 1 and Bruce 5, March 1.
- May 1, the AECB rules that women who are not pregnant will be allowed to work under the same radiation protection limits as men. Skilled tradeswomen can now work in Hydro's nuclear program.
- Select Committee on Energy is appointed to assess the need to complete Darlington. It will recommend that the power will be needed and the station is too far along to be cancelled.

1986

- Pickering 8 is in service on February 28. The station is complete.
- March 28, a pressure tube and its calandria tube in Bruce 2 rupture when the shutdown reactor is repressurized to locate a small leak. Bits of a fuel pencil are found in the moderator. There is no release of radioactivity but repairs take several months.
- March 1986, Gentilly 1 is put in Phase II decommissioning state.
- April 10, Bruce 7 comes into service.
- In July, the Select Committee on Energy issues its final report and recommends the establishment of an independent safety review of Ontario Hydro's operating nuclear plants.
- December 1986, the Ministry of Energy appoints Dr. Kenneth Hare to head an inquiry into the safety of nuclear power in Ontario. The Minister also instigates the process to arrange for a review of Pickering operating practices by a mission from the International Atomic Energy Agency (IAEA).

1987

- NPD is shut down May 25 for semi-annual maintenance and pressure tube inspection which reveals that the reactor needs retubing. Since the station's output is small and it has fulfilled its role as a demonstration power reactor, Hydro and AECL decide retubing is not economical, and on July 24 recommend the station be shut down.
- June 1-19 the IAEA Operational Safety Review team (OSART) studies the Pickering Nuclear Generating Station.
- Bruce 8, the final unit at the station, is declared in service May 22.
- Pickering 1 is returned to service October 1, after retubing.

1987 (Cont'd)

- The OSART report on Pickering is made public on September 24. The IAEA mission concludes that the "safety status of the station was satisfactory and no shortcomings with equipment, personnel or operating practise were found that would threaten the continuation of safe and reliable electricity generation."

1988

- February 11, a Select Committee on Energy is appointed to report back to the Ontario Legislature by December 31, 1988, on public views and concerns about Hydro's draft Demand/Supply Planning Strategy, which examines possible options for meeting the demand for electricity in the year 2000 and beyond.
- Dr. Hare issues report on safety of Ontario Hydro nuclear plants which concludes that the reactors "are being operated safely and at a high standard of technical performance".
- March 14, Ontario Hydro Board of Directors approves $500-million advanced retubing for Pickering 3 and 4.

—Expected—

1988

- Pickering 2 will be back in service in the fall after being retubed.
- Tritium Removal Facility at Darlington is scheduled for completion in the fall.

1989

- Pickering 3 to be shut down for retubing.
- Darlington 1 in service.

1990

- Darlington 2 in service.
- In August, construction will be completed on a second 500-kilovolt line out of the Bruce Nuclear Power Development, making transmission facilities adequate to run all eight reactors at capacity.

1991

- Darlington 3 in service.
- Pickering 3 retubed and returned to service.
- Pickering 4 to be shut down for retubing when Pickering 3 is completed.

1992

- Darlington 4 in service.

1993

- Pickering 4 retubed and returned to service.

Note

1. For more information on the specifics of each Ontario Hydro nuclear station, see **Station Stats.**
2. *Canada's Nuclear Story,* by Wilfred Eggleston, was the source for the years 1928 to 1951. See **Publications.**

Ontario Hydro Generating Unit Service Dates

Annual Peak Demand*	Hydro	Fossil Fuels	Nuclear
1945 MAXIMUM 20 MINUTE PEAK—1,771.3 MW			
1946 MAXIMUM 20 MINUTE PEAK—2,036.1 MW			
1947 MAXIMUM 20 MINUTE PEAK—2,262.2 MW			
1948 MAXIMUM 20 MINUTE PEAK—2,393.0 MW	AQUASABON In Service 40.5 MW HYDRO; STEWARTVILLE In Service 153 MW HYDRO		
1949 MAXIMUM 20 MINUTE PEAK—2,443.7 MW			
1950 MAXIMUM 20 MINUTE PEAK—2,753.1 MW	CHENAUX In Service 122.4 MW HYDRO; DES JOACHIMS In Service 360 MW HYDRO; PINE PORTAGE In Service 128.7 MW HYDRO; G.W. RAYNER In Service 42.3 MW HYDRO		
1951 MAXIMUM 20 MINUTE PEAK—3,063.1 MW		R.L. HEARN 1 In Service 100 MW COAL	
1952 MAXIMUM 20 MINUTE PEAK—3,247.7 MW	OTTO HOLDEN In Service 205.2 MW HYDRO	R.L. HEARN 2 In Service 100 MW COAL; J.C. KEITH 2 In Service 66 MW COAL; J.C. KEITH 1 In Service 66 MW COAL; R.L. HEARN 3 In Service 100 MW COAL	
1953 MAXIMUM 20 MINUTE PEAK—3,442.8 MW		J.C. KEITH 3 In Service 66 MW COAL; R.L. HEARN 4 In Service 100 MW COAL; J.C. KEITH 4 In Service 66 MW COAL	
1954 MAXIMUM 20 MINUTE PEAK—3,655.7 MW	SIR ADAM BECK—NIAGARA 2 In Service 1223.6 MW HYDRO		
1955 MAXIMUM 20 MINUTE PEAK—4,183.2 MW			
1956 MAXIMUM 20 MINUTE PEAK—4,468.5 MW	MANITOU FALLS In Service 72 MW HYDRO		
1957 MAXIMUM 20 MINUTE PEAK—4,737.6 MW	NIAGARA PUMPING—GENERATING In Service 176.7 MW HYDRO		
1958 MAXIMUM 20 MINUTE PEAK—5,093.1 MW	CARIBOU FALLS In Service 76.95 MW HYDRO; R.H. SAUNDERS In Service 912 MW HYDRO; WHITEDOG FALLS In Service 64.8 MW HYDRO		
1959 MAXIMUM 20 MINUTE PEAK—5,510.6 MW	SILVER FALLS In Service 45 MW HYDRO		

1960 MAXIMUM 20 MINUTE PEAK—5,699.8 MW	**RED ROCK FALLS** In Service 40.5 MW **HYDRO**	**R.L. HEARN 6** In Service 200 MW **COAL**									
1961 MAXIMUM 20 MINUTE PEAK—5,902.9 MW	**OTTER RAPIDS** In Service 174.8 MW **HYDRO**	**R.L. HEARN 5** In Service 200 MW **COAL**	**R.L. HEARN 7** In Service 200 MW **COAL**	**R.L. HEARN 8** In Service 200 MW **COAL**							
1962 MAXIMUM 20 MINUTE PEAK—6,247.0 MW		**LAKEVIEW 1** In Service 300 MW **COAL**								**NPD** In Service 25 MW **NUCLEAR**	
1963 MAXIMUM 20 MINUTE PEAK—6,750.6 MW	**LITTLE LONG** In Service 121.6 MW **HYDRO**	**LAKEVIEW 2** In Service 300 MW **COAL**		**THUNDER BAY 1** In Service 100 MW **COAL**					**THUNDER BAY 1** Mothballed 100 MW **COAL**		
1964 MAXIMUM 20 MINUTE PEAK—7,163.9 MW											
1965 MAXIMUM 20 MINUTE PEAK—7,818.4 MW	**HARMON** In Service 129.2 MW **HYDRO**	**LAKEVIEW 3** In Service 300 MW **COAL**	**LAKEVIEW 4** In Service 300 MW **COAL**								
1966 MAXIMUM 20 MINUTE PEAK—8,565.6 MW	**KIPLING** In Service 125.4 MW **HYDRO**	**THUNDER BAY 1** Recommissioned 100 MW **COAL**									
1967 MAXIMUM 20 MINUTE PEAK—8,963.8 MW	**MOUNTAIN CHUTE** In Service 139.5 MW **HYDRO**	**LAKEVIEW 5** In Service 300 MW **COAL**									
1968 MAXIMUM 20 MINUTE PEAK—9,994.4 MW										**DOUGLAS POINT** In Service 200 MW **NUCLEAR**	
1969 MAXIMUM 20 MINUTE PEAK—10,555.4 MW	**AUBREY FALLS** In Service 130.2 MW **HYDRO**	**LAKEVIEW 6** In Service 300 MW **COAL**	**LAKEVIEW 7** In Service 300 MW **COAL**	**LAKEVIEW 8** In Service 300 MW **COAL**	**LAMBTON 2** In Service 500 MW **COAL**						
1970 MAXIMUM 20 MINUTE PEAK—11,288.7 MW	**WELLS** In Service 203.3 MW **HYDRO**	**LAMBTON 1** In Service 500 MW **COAL**	**LAMBTON 3** In Service 500 MW **COAL**	**LAMBTON 4** In Service 500 MW **COAL**							
1971 MAXIMUM 20 MINUTE PEAK—11,534.5 MW	**LOWER NOTCH** In Service 228 MW **HYDRO**	**R.L. HEARN 1** Recommissioned 100 MW **GAS**	**R.L. HEARN 2** Recommissioned 100 MW **GAS**	**R.L. HEARN 3** Recommissioned 100 MW **GAS**	**R.L. HEARN 4** Recommissioned 100 MW **GAS**	**R.L. HEARN 5** Recommissioned 200 MW **GAS/COAL**	**R.L. HEARN 8** Recommissioned 200 MW **GAS/COAL**			**PICKERING 1** In Service 542 MW **NUCLEAR**	**PICKERING 2** In Service 542 MW **NUCLEAR**
1972 MAXIMUM 20 MINUTE PEAK—12,738.8 MW		**R.L. HEARN 6** Recommissioned 200 MW **GAS/COAL**	**R.L. HEARN 7** Recommissioned 200 MW **GAS/COAL**							**PICKERING 3** In Service 542 MW **NUCLEAR**	
1973 MAXIMUM 20 MINUTE PEAK—13,605.4 MW		**NANTICOKE 2** In Service 500 MW **COAL**	**NANTICOKE 1** In Service 500 MW **COAL**	**NANTICOKE 3** In Service 500 MW **COAL**						**PICKERING 4** In Service 542 MW **NUCLEAR**	
1974 MAXIMUM 20 MINUTE PEAK—13,538.1 MW		**NANTICOKE 4** In Service 500 MW **COAL**									
1975 MAXIMUM 20 MINUTE PEAK—14,512.5 MW		**NANTICOKE 5** In Service 500 MW **COAL**									
1976 MAXIMUM 20 MINUTE PEAK—15,895.3 MW	**ARNPRIOR** In Service 74 MW **HYDRO**	**LENNOX 1** In Service 558 MW **OIL**	**LENNOX 2** In Service 558 MW **OIL**	**LENNOX 3** In Service 558 MW **OIL**		**J.C. KEITH 1** Mothballed 66 MW **COAL**	**J.C. KEITH 2** Mothballed 66 MW **COAL**	**J.C. KEITH 3** Mothballed 66 MW **COAL**	**J.C. KEITH 4** Mothballed 66 MW **COAL**		
1977 MAXIMUM 20 MINUTE PEAK—15,901.1 MW		**NANTICOKE 6** In Service 500 MW **COAL**	**LENNOX 4** In Service 558 MW **OIL**							**BRUCE 1** In Service 815 MW **NUCLEAR**	**BRUCE 2** In Service 815 MW **NUCLEAR**
1978 MAXIMUM 20 MINUTE PEAK—16,246.7 MW		**NANTICOKE 8** In Service 500 MW **COAL**	**NANTICOKE 7** In Service 500 MW **COAL**					**WESLEYVILLE 1** Cancelled 500 MW **OIL**	**WESLEYVILLE 2** Cancelled 500 MW **OIL**	**BRUCE 3** In Service 815 MW **NUCLEAR**	

1979 MAXIMUM 20 MINUTE PEAK—16,364.7 MW					WESLEYVILLE 3 Stop Build 500 MW OIL	WESLEYVILLE 4 Stop Build 500 MW OIL	R.L. HEARN 1 Mothballed 100 MW GAS	R.L. HEARN 2 Mothballed 100 MW GAS	R.L. HEARN 3 Mothballed 100 MW GAS	BRUCE 4 In Service 815 MW NUCLEAR		
1980 MAXIMUM 20 MINUTE PEAK—16,807.8 MW		J.C. KEITH 1 Recommissioned 66 MW COAL	J.C. KEITH 2 Recommissioned 66 MW COAL	J.C. KEITH 3 Recommissioned 66 MW COAL	J.C. KEITH 4 Recommissioned 66 MW COAL	R.L. HEARN 4 Mothballed 100 MW GAS	R.L. HEARN 5 Mothballed 200 MW GAS/COAL	LENNOX 3 Mothballed 558 MW OIL	LENNOX 4 Mothballed 558 MW OIL			
1981 MAXIMUM 20 MINUTE PEAK—17,189.0 MW		THUNDER BAY 2 In Service 155 MW LIGNITE						WESLEYVILLE 3 Cancelled 500 MW OIL	WESLEYVILLE 4 Cancelled 500 MW OIL			
1982 MAXIMUM 20 MINUTE PEAK—18,123.6 MW		THUNDER BAY 3 In Service 155 MW LIGNITE					LENNOX 1 Mothballed 558 MW OIL	LENNOX 2 Mothballed 558 MW OIL	ATIKOKAN 2 Cancelled 200 MW LIGNITE			
1983 MAXIMUM 20 MINUTE PEAK—18,791.5 MW					J.C. KEITH 1 Mothballed 66 MW COAL	J.C. KEITH 2 Mothballed 66 MW COAL	R.L. HEARN 6 Mothballed 200 MW GAS/COAL	R.L. HEARN 7 Mothballed 200 MW GAS/COAL	R.L. HEARN 8 Mothballed 200 MW GAS/COAL	PICKERING 5 In Service 540 MW NUCLEAR	PICKERING 1 Out For Retubing 542 MW NUCLEAR	PICKERING 2 Out For Retubing 542 MW NUCLEAR
1984 MAXIMUM 20 MINUTE PEAK—18,896.0 MW							THUNDER BAY 1 Mothballed 100 MW COAL	J.C. KEITH 3 Mothballed 66 MW COAL	J.C. KEITH 4 Mothballed 66 MW COAL	PICKERING 6 In Service 540 MW NUCLEAR	BRUCE 6 In Service 890 MW NUCLEAR	DOUGLAS POINT Closed 200 MW NUCLEAR
1985 MAXIMUM 20 MINUTE PEAK—20,473.0 MW										PICKERING 7 In Service 540 MW NUCLEAR	BRUCE 5 In Service 890 MW NUCLEAR	
1986 MAXIMUM 20 MINUTE PEAK—20,668.0 MW										PICKERING 8 In Service 540 MW NUCLEAR	BRUCE 7 In Service 890 MW NUCLEAR	
1987 MAXIMUM 20 MINUTE PEAK—22,578.0 MW**		LENNOX 1 Recommissioned 558 MW OIL	LENNOX 2 Recommissioned 558 MW OIL							BRUCE 8 In Service 890 MW NUCLEAR	PICKERING 1 Back From Retubing 542 MW NUCLEAR	NPD Shut Down 25 MW NUCLEAR
1988		LENNOX 4 Recommissioned 558 MW OIL								PICKERING 2 Back From Retubing 542 MW NUCLEAR		
1989										DARLINGTON 1 In Service 900 MW NUCLEAR		PICKERING 3 Out For Retubing 542 MW NUCLEAR
1990										DARLINGTON 2 In Service 900 MW NUCLEAR		
1991										DARLINGTON 3 In Service 900 MW NUCLEAR	PICKERING 3 Back From Retubing 542 MW NUCLEAR	PICKERING 4 Out For Retubing 542 MW NUCLEAR
1992										DARLINGTON 4 In Service 900 MW NUCLEAR		
1993										PICKERING 4 Back From Retubing 542 MW NUCLEAR		

*Beginning in 1970, the maximum 20-minute peak is the co-incident East-West System peak of Northwestern Ontario and the rest of the province (the transmission system between the two areas is limited—much of the electricity used in the northwest is generated there).

**preliminary number.

Most of Ontario's electrical system has been built since the Second World War. Until that time, all electricity in Ontario was generated from hydro-electric power. Through the 1950s and 1960s, demand for electricity grew at seven per cent a year: generating capacity had to double every 10 years. The large hydro-electric projects of the 1950s, Sir Adam Beck 2 and Robert H. Saunders, were built on the two sites in the province suitable for hydro-electric stations on that scale. While Ontario Hydro continues to build hydro-electric stations on suitable smaller sites, it has had to turn to coal, uranium, gas and oil to generate the electricity the province needs.

Reactor Rankings

Reactor Rankings

World Top 15 for 1987 Performance

Units 500 MWe (gross) and over which produced electricity prior to January 1, 1987

Ranking	Country	Unit	Reactor Type*	Gross MCR (MWe)	Years in Service	Gross Capacity Factor (%)**
1	Japan	Ikata 1	PWR	566	10	99.9
2	Japan	K-Kariwa 1	BWR	1,100	2	99.6
3	Japan	Hamaoka 2	BWR	840	9	98.6
4	Canada	Pickering 7	CANDU	540	3	96.8
5	Belgium	Tihange 1	PWR	920	9	96.0
6	Canada	Bruce 6	CANDU	890	3	95.9
7	U.S.A.	Prairie Island 2	PWR	560	13	95.4
8	Japan	Ohi 1	PWR	1,175	8	95.2
9	S. Korea	Kori 1	PWR	587	9	94.0
10	W. Germany	Isar 1	BWR	907	8	93.9
11	U.S.A.	Susquehanna 2	BWR	1,085	2	93.7
12	S. Korea	Wolsung	CANDU	679	5	92.8
13	Spain	Almaraz 1	PWR	930	6	92.4
14	Finland	Olkiluoto 2	BWR	735	7	92.3
15	U.S.A..	Millstone 2	PWR	889	12	91.9

World Top 15 for Lifetime Performance

Ranking	Country	Unit	Reactor Type*	Gross MCR (MWe)	Years in Service	Gross Capacity Factor (%)***
1	Canada	Pt. Lepreau	CANDU	680	4	87.5
2	Canada	Pickering 7	CANDU	540	3	87.3
3	Canada	Bruce 3	CANDU	904	9	86.9
4	Canada	Pickering 8	CANDU	540	1	86.8
5	Canada	Bruce 6	CANDU	890	3	86.2
6	Canada	Bruce 7	CANDU	890	1	85.6
7	W. Germany	Philippsburg 2	PWR	1,350	2	85.4
8	W. Germany	Grohnde A 1	PWR	1,365	2	85.1
9	Canada	Bruce 4	CANDU	904	8	84.7
10	Belgium	Tihange 3	PWR	1,048	2	84.1
11	W. Germany	Stade 1	PWR	672	15	84.0
12	Canada	Bruce 5	CANDU	885	2	84.0
13	W. Germany	Grafenrheinfeld	PWR	1,290	6	83.5
14	Japan	Genkai 2	PWR	559	6	82.9
15	Belgium	Doel 3	PWR	936	5	82.7

* Reactor types are explained on pages 70 to 73.

** Gross capacity factor is the amount of energy the reactor produced in a given period, expressed as a percentage of perfect performance—continuous, full-power output—which would be 100 per cent.

*** See note above. Lifetime means since first electricity production.

1987 Performance of Ontario Hydro Units†

World Rank	Unit	Gross Capacity Factor (%)*
4	Pickering 7	96.8
6	Bruce 6	95.9
21	Pickering 6	88.3
26	Bruce 7	86.5
38	Pickering 8	84.0
39	Pickering 4	84.0
50	Bruce 3	82.1
62	Pickering 5	80.6
70	Bruce 5	79.1
85	Pickering 3	76.9
143	Bruce 4	68.3
189	Bruce 1	59.9
216	Bruce 2	50.9
239	Pickering 1	18.9
247	Pickering 2	0.0

*Gross capacity factor is the amount of energy the reactor produced in a given period, expressed as a percentage of perfect performance—continuous, full-power output—which would be 100 per cent.

†Units 500 MWe (gross) and over which produced electricity prior to January 1, 1987

Lifetime Performance of Ontario Hydro Units**

World Rank	Unit	Gross Capacity Factor (%)(1)*
2	Pickering 7	87.3
3	Bruce 3	86.9
4	Pickering 8	86.8
5	Bruce 6	86.2
6	Bruce 7	85.6
9	Bruce 4	84.7
12	Bruce 5	84.0
16	Pickering 4	82.1
21	Bruce 1	80.4
23	Pickering 5	79.6
27	Pickering 6	79.3
40	Pickering 3	77.4
70	Bruce 2	71.9
146	Pickering 1	61.5
150	Pickering 2	60.8

*Gross capacity factor is the amount of energy the reactor produced in a given period, expressed as a percentage of perfect performance—continuous, full-power output—which would be 100 per cent.

(1) Since first electricity production.

**These lifetime rankings are based on performance since first electricity production. They are significantly different from those appearing in some nuclear publications (among them, *Nucleonics Week*) which are calculated from each unit's in-service date.

1985 International Comparison of Electricity Generation †

Country	Total (Millions kWhrs)	% Thermal	% Hydro	% Nuclear	% Other
Canada	460,408 (38,870)	21 (2)	66 (7)	13	
France*	326,400 (29,300)	16 (7)	19 (2)	65	
W. Germany	406,714 (62,227)	65 (15)	4 (0.5)	31 (0.3)	
Japan	673,412 (68,276)	63 (9)	13 (1)	24 (0.1)	0.2 (0.04)
U.K.	294,722 (17,581)	78 (4)	1 (0.2)	21 (2)	
U.S.**	2,525,191 (55,350)	73 (2)	11 (0.05)	15	0.4
USSR	1,544,000 (78,600)	76 (5)	13 (0.04)	11	

†This table is based on data from *1985 Energy Statistics Yearbook*. Table 34. New York: United Nations, 1987. Percentages were calculated and rounded up to the nearest digit.

Thermal production refers to electricity generated from burning coal, gas or oil, whether or not the plants are equipped for the combined generation of heat and electricity.

Data for U.S. thermal cogeneration production and Soviet hydro and thermal cogeneration production are United Nations Statistical Office estimates.

Unless otherwise indicated, the data in this table refers to gross production. It includes the consumption by station auxiliaries and any losses in the transformers that are considered integral parts of the station. It excludes, however, energy production from pumped storage.

( ) Contribution of cogenerating power plants (undertakings which produce electric energy intended, in whole or in part, to meet their own needs), broken out from the top-line figure, the total electricity production and per cent contribution by type.

*Production for France (including Monaco) refers to net production.

**Production for the United States refers to net production.

Note:

1) By 1990, there will be more than 500 power reactors in service in the non-communist world. With a combined capacity of about 400,000 megawatts, they will be able to produce more electricity than all the world's hydro-electric plants.
2) About 30 per cent of the industrialized world's energy sources are now used to generate electricity. This will likely reach 40 per cent by the year 2000.

Electricity Rates Compared

Monthly Residential Bills
1,000 kW.h, September 1987*

Chicago	$221	(164)
New York	180	(134)
Boston	134	(99)
St. Louis	125	(93)
Detroit	119	(88)
Little Rock	110	(82)
Washington, D.C.	109	(81)
Tampa	103	(76)
Los Angeles	101	(75)
Atlanta	94	(70)
Birmingham	92	(68)
Louisville	89	(66)
Charlottetown	81	
Tennessee Valley Authority	74	(55)
Halifax	72	
St. John's	69	
Portland, Oregon	65	(48)
Fredericton	65	
Ontario—Rural	63	
Ontario—Municipal Electric Utility Average	56	
Regina	55	
Vancouver	53	
Calgary	50	
Montreal	44	
Winnipeg	43	

* Bills for U.S. cities have been converted into Canadian dollars on the basis of a $1.347 U.S. dollar (equivalent U.S. dollars are in brackets).

Production & Consumption

Production &
Consumption

Production and Consumption Notes

Growth in Energy Consumption

The amount of energy mankind has consumed since the beginning of time will likely be matched in the next 25 years.

To date, an estimated 10 million exajoules of energy (10 million quadrillion BTUs) have been consumed. If the past decade's 1.8 per cent growth in energy use continues, another 10 million exajoules will be consumed by 2012.

Exponential Growth—Rules of Thumb

If energy use grows *2.3 per cent* a year, consumption will *double in 30 years.*

If energy use grows *3.5 per cent* a year, consumption will *double in 20 years.*

If energy use grows *seven per cent* a year, consumption will *double in 10 years.*

Ontario Consumption

As a rule of thumb, **you can count on three kilowatts of electricity being consumed per household at the time of peak demand.** So a 540-megawatt Pickering unit would serve roughly 180,000 households.

Since the electricity produced at all Hydro plants flows into the central electrical grid which supplies power to all electricity users—industrial and commercial as well as residential—one can't precisely say what the electricity from a specific reactor was used for. It is accurate, however, to say, "unit X, now down for repairs, produces X megawatts of electricity, enough to supply the peak electricity needs of X households."

Ontario Electrical Consumption by Sector

In 1987, 115.8 terawatt-hours of electricity were consumed in Ontario: approximately 28 per cent by the residential sector (includes agricultural); 36 per cent by the commercial sector (offices, apartments, stores, hospitals, schools and hotels); 36 per cent by the industrial sector. (Note: data is preliminary.)

Ontario Electrical Production by Source

In 1987, nuclear power supplied 47.5 per cent of the electricity consumed in Ontario. Hydro-electric and fossil (coal and oil) generation each supplied 23.8 and 23.9 per cent, respectively, of the province's electricity. The remaining 4.8 per cent of electricity used was purchased from Manitoba, Quebec, Michigan, New York and from individuals and companies in Ontario that generate electricity themselves.

Conversion Tables

Conversion Tables

From Mega to Kilo

Prefix	(symbol)	Unit Being Used (i.e., Watt, Gram, Curie)	Multiplying Factor	Factor name
exa	(E)	+ unit	= unit x 10^{18}	
peta	(P)	+ unit	= unit x 10^{15}	quadrillion*
tera	(T)	+ unit	= unit x 10^{12}	trillion*
giga	(G)	+ unit	= unit x 10^{9}	billion*
mega	(M)	+ unit	= unit x 10^{6} (1,000,000)	million
kilo	(k)	+ unit	= unit x 10^{3} (1,000)	thousand
hecto	(h)	+ unit	= unit x 10^{2} (100)	hundred
deca	(da)	+ unit	= unit x 10^{1} (10)	ten
deci	(d)	+ unit	= unit x 10^{-1} (0.1)	tenth part
centi	(c)	+ unit	= unit x 10^{-2} (0.01)	hundredth part
milli	(m)	+ unit	= unit x 10^{-3} (0.001)	thousandth part
micro	(μ)	+ unit	= unit x 10^{-6} (0.000 001)	millionth part
nano	(n)	+ unit	= unit x 10^{-9}	billionth part*
pico	(p)	+ unit	= unit x 10^{-12}	trillionth part*
femto	(f)	+ unit	= unit x 10^{-15}	quadrillionth part*
atto	(a)	+ unit	= unit x 10^{-18}	

*These names are used in Canada and the United States. In Great Britain, 10^{12} is a billion, 10^{18} is a trillion and 10^{24} is a quadrillion.

Note:

The exponent equals the number of digits between the unit used and the basic unit (watt, curie, etc.).

Multiples of the basic unit
A kilowatt is a unit with three zeros after it, or 1,000 watts:

1 watt x 10^3 = 1,000 watts = 1 kilowatt

Fractions of the basic unit
A nanocurie is a fraction of a curie occupying nine digits after the decimal point:

1 curie x 10^{-9} = .000 000 001 curie = 1 nanocurie

Remember that on the decimal side, there is one less zero than the exponential number because the exponent represents not the number of zeros, but the number of digits away from the basic unit.

To express 2,350 nanocuries with a decimal point, replace the last four digits:

1 nanocurie = 0.000 000 001
2,350 nanocuries = 0.000 002 350

Converting Between Radiological Units

From curie to becquerel

kilocurie (kCi) = 37 terabecquerel (TBq)
curie (Ci) = 37 gigabecquerel (GBq)
millicurie (mCi) = 37 megabecquerel (MBq)
microcurie (μCi) = 37 kilobecquerel (kBq)
nanocurie (nCi) = 37 becquerel (Bq)
picocurie (pCi) = 37 millibecquerel (mBq)

From becquerel to curie

1 terabecquerel (TBq) = 27 curie (Ci)
1 gigabecquerel (GBq) = 27 millicurie (mCi)
1 megabecquerel (MBq) = 27 microcurie (μCi)
1 kilobecquerel (kBq) = 27 nanocurie (nCi)
1 becquerel (Bq) = 27 picocurie (pCi)

From rem to sievert

kilorem (krem) = 10 sievert (Sv)
rem (rem) = 10 millisievert (mSv)
millirem (mrem) = 10 microsievert (μSv)
microrem (μrem) = 10 nanosievert (nSv)

From sievert to rem

1 sievert (Sv) = 100 rem (rem)
1 millisievert (mSv) = 100 millirem (mrem)
1 microsievert (μSv) = 100 microrem (μrem)
1 nanosievert (nSv) = 100 nanorem (nrem)

From rad to gray

kilorad (krad) = 10 gray (Gy)
rad (rad) = 10 milligray (mGy)
millirad (mrad) = 10 microgray (μGy)
microrad (μrad) = 10 nanogray (nGy)

From gray to rad

1 gray (Gy) = 100 rad (rad)
1 milligray (mGy) = 100 millirad (mrad)
1 microgray (μGy) = 100 microrad (μrad)
1 nanogray (nGy) = 100 nanorad (nrad)

From roentgen to coulomb/kg

kiloroentgen (kR) = 258 millicoulomb/kg (mC/kg)
roentgen (R) = 258 microcoulomb/kg (μC/kg)
milliroentgen (mR) = 258 nanocoulomb/kg (nC/kg)
microroentgen (μR) = 258 picocoulomb/kg (pC/kg)

From coulomb/kg to roentgen

1 coulomb/kg = 3876 roentgen (R)
1 millicoulomb/kg (mC/kg) = 3876 milliroentgen (mR)
1 microcoulomb/kg (μC/kg) = 3876 microroentgen (μR)
1 nanocoulomb/kg (nC/kg) = 3876 nanoroentgen (nR)

Getting The Answers

Media Relations

Media Relations

24 Hours A Day, Seven Days A Week

Reporters can reach the Ontario Hydro media relations newsdesk on weekdays from 7:30 a.m. to 5 p.m. at (416) 592-2056, 3338. After 5 p.m. and on weekends and statutory holidays, a duty officer is on call. Just call (416) 592-2056, leave your name and number and you will be called back within half an hour.

Provincial Emergency Plan

The Ministry of the Solicitor General has responsibility for developing and overseeing, with Ontario Hydro and municipal officials, the Ontario Nuclear Contingency Plan. The plan would go into effect if there were an accident at a nuclear plant which released, or had the potential of releasing, large quantities of radioactive liquid or steam which was likely to travel beyond the one kilometre (0.6 mile) exclusion zone around the plant. This is the worst possible scenario of a CANDU nuclear plant accident. The plan could involve evacuation of a 10-kilometre (six-mile) radius around the plant and distribution of potassium iodide pills for thyroid blocking.

A Provincial Information Centre would be set up at Ontario Hydro's 700 University Avenue building. The usual Media Relations phone numbers—(416) 592-2056, 3338, 3339, 3340—would be in operation. Reporters should call them, or come to the Provincial Information Centre, when it is fully set up. They would not be allowed access to the affected station.

Nuclear station employees are continually drilled on their role in the plan.

Questions To Ask

An off-site nuclear emergency would be an extremely unlikely occurrence. Occasionally, there have been fairly major incidents at Hydro nuclear plants—the most expensive and extensive was the August 1, 1983 pressure tube rupture at the Pickering Nuclear Generating Station.

Frequently, reactors are shut down for maintenance, or because one of their sensitive safety systems trips when there is no real need, or because of small leaks somewhere in their labyrinth of piping, or because of a problem with the turbine generator.

When any of the above occur, reporters often ask Media Relations for a sense of the relative significance of the shutdown. Two of the most frequently asked questions are certainly valid, but difficult to answer at the time: how long will repairs last and how much will they cost? When a problem has just occurred, the answer to both is usually, "it's too soon to tell".

Cost can be difficult to calculate because three things have to be considered: the cost of repairing the unit; the cost of replacing the power with another, usually more expensive source; and finally, the accounting, operating and scheduling measures which can be taken to minimize the cost. For instance, if reactor A is scheduled to be shut down next week for a month's routine maintenance and reactor B is slated for the same in four months, then reactor B develops a major problem and is quickly shutdown, the planned maintenance times for the two units can be switched so that there will be little actual cost for the shutdown.

Many of the reporters canvassed for their ideas about the content of this handbook asked for guidelines to help them determine the relative significance of a forced shutdown at a nuclear plant. The questions on the following page might serve as a check-list.

Shutdown Check-list

What happened? ______

When? ______

When discovered? ______

Was anyone killed? ______

Was anyone hurt? ______

Did any worker receive a high exposure to radiation? ______

How does it relate to AECB limits? ______

Is the person in the hospital? ____ At home? ____

Will the person be able to continue working at his/her regular job? ______

Were there any emissions to the air? ______

Water? ____ Land? ____ Amount of emission? ____

Relative to Atomic Energy Control Board (AECB) limits? ______

Who have you notified? ______

Was this a process system or safety system fault?

______

Where is the problem (ie. reactor? vault? turbine?)

______

Was the reactor in operation or shut down? ______

Was this a loss-of-coolant (heavy water from heat transport system) accident? ______

How does it compare in severity to the pressure tube rupture at Pickering in 1983? ______

How long will the reactor be shutdown? ______

When will you have an idea of the cost of the outage? ______

How many megawatts did the reactor produce? ______

How are you making up the lost generation? Burning coal? Buying electricity? From where? ______

Are you cutting sales or interrupting customers? Reducing voltage? ______

Sources

Sources

Sources

Major Canadian Electrical Utilities

Alberta

Transalta Utilities Corporation (private sector)
(403) 267-7110
(403) 267-7338—Public Affairs

Alberta Power Limited (private sector)
(403) 420-7310
(403) 420-7088—Public Relations

British Columbia

British Columbia Hydro (public sector)
(604) 663-2212—ask for Communications Department

Manitoba

Manitoba Hydro (public sector)
(204) 474-3311—ask for Public Affairs

New Brunswick

New Brunswick Power (public sector)
(506) 458-4444—ask for Public Relations

Newfoundland

Newfoundland Light & Power Company Limited
(private sector)
(709) 737-5600
(709) 737-5764—Public Affairs

Newfoundland and Labrador Hydro (public sector)
(709) 737-1400
(709) 737-1290—Public Affairs

Churchill Falls (Labrador) Corporation Limited
(public sector)
(709) 737-1450
(709) 737-1290—Public Affairs

Northwest Territories and the Yukon

Northern Canada Power Commission (public sector)
(403) 465-3377—ask for Corporate Affairs

Nova Scotia

Nova Scotia Power (public sector)
(902) 428-6230
(902) 428-6394—Public Relations

Ontario

Ontario Hydro (public sector)
(416) 592-5111
(416) 592-3338—Media Relations
(416) 592-2056—after hours Media Relations

Canadian Niagara Power Company Ltd. (private sector)
(416) 354-1641—ask for Public Relations

Great Lakes Power Company Limited Utilities Division
(private sector)
(705) 759-7600
(705) 759-7627—Public Relations

Cornwall Electric (formerly St. Lawrence Power Company)
(private sector)
(613) 932-1404—ask for Public Affairs

Prince Edward Island

Maritime Electric Company Limited (private sector)
(902) 566-1599—ask for Public Relations

Quebec

Hydro-Quebec (public sector)
(514) 289-2211
(514) 289-2312—Media Relations

Saskatchewan

Saskatchewan Power Corporation (public sector)
(306) 566-2121
(306) 566-3166—Media Relations

Organizations

Atomic Energy Control Board (AECB)

(613) 995-5894—Office of Public Information

Atomic Energy of Canada Limited (AECL)

(613) 237-3270—Corporate Office, Media Relations
(416) 823-2480—CANDU Operations, Media Relations

CAE Electronics

(416) 865-0070

Manufactures control room simulators for Ontario Hydro reactors as well as for some American utilities.

Canadian Electrical Association (CEA)

(514) 937-6181

National association of Canadian electrical utilities.

Canadian Fusion Fuels Technology Project

(416) 823-0200

A national research program which co-ordinates Canada's contribution to international fusion power development programs. It is managed by Ontario Hydro.

Canadian Institute for Radiation Safety (CAIRS)

(416) 596-1617—Toronto
(705) 848-3687—Elliot Lake

An independent, non-profit national institute dedicated solely to radiation safety, with emphasis on the uranium mining industry.

Canadian Nuclear Association (CNA)

(416) 977-6152

Association of companies and utilities promoting peaceful uses of nuclear power, established in 1960.

Canadian Nuclear Society (CNS)

(416) 977-7620

Technical association of engineers and scientists working in the Canadian nuclear industry, established in 1979.

Canadian Radiation Protection Association

(613) 237-3392

A professional association of radiation protection specialists dedicated to developing and publicizing scientific knowledge and practical means for protecting man and his environment from the harmful effects of radiation, while pursuing the optimum use of radiation for the benefit of mankind. Spokespersons can address a variety of subjects.

Electric Power Research Institute (EPRI)

(415) 855-2413—Media Relations

Manages research and development for the U.S. electric utility industry. Can comment on a broad range of topics concerning electrical technology.

Energy Probe

(416) 978-7014

Anti-nuclear lobby group. The most consistent critic of Ontario Hydro, challenging the utility in the media and the courts. Spokespersons available on a variety of subjects.

Health and Welfare Canada, Bureau of Radiation and Medical Devices

(613) 957-1803—Media Relations

International Atomic Energy Agency (IAEA)

011-43-222-2360—Vienna

United Nations agency which conducts on-site inspections of nuclear facilities in the western world, sets international standards for operation and safety of nuclear facilities and facilitates the exchange of scientific and engineering data.

Institute of Nuclear Power Operations (INPO)

(404) 953-3600

INPO was established in December, 1979, by the U.S. nuclear utility industry in the wake of the Three Mile Island accident. Sponsored by its 55 member utilities, INPO runs programs to promote improved safety and reliability in nuclear plant operations.

International Commission on Radiological Protection (ICRP)

Clifton Avenue
Sutton, Surrey SM2 5PU
United Kingdom

Founded in 1928, the ICRP is an independent, non-government expert body whose members are chosen on the basis of individual merit in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry, biophysics. Through review of the latest research, the ICRP establishes basic principles on which most countries base their radiation protection measures.

Institute for Risk Research, University of Waterloo

(519) 885-1211, ext. 3355

The only institute of its kind in Canada, it can comment on the total benefits/risks of different energy technologies.

Labour Canada, Occupational Health and Safety

(613) 953-0168—Media Relations

Legislative Library, Research and Information Services

(416) 965-4545

Ontario government library contains all provincial government reports from standing and select committees. Also contains Hydro reports, including Significant Event Reports on nuclear station operations.

Ministry of the Solicitor General

(416) 965-6932—Coordinator of Emergency Planning,
Ken Reeves
(416) 965-6708 Head, Plans and Operations, Farouk Ali

The Ministry is responsible for nuclear emergency planning.

Nuclear Energy Agency (NEA)

38, boulevard Suchet 75016, Paris, France
Telephone: 524.96.67 Telex: AEN/NEA 630668

Operates under the aegis of the Organization for Economic Co-operation and Development (OECD) to facilitate the exchange of information among member countries.

Nuclear Regulatory Commission

(301) 492-0240—Public Affairs

Regulatory body for the American nuclear power program.

Ontario Hydro Employees Union (OHEU)

(416) 481-4492—Bob Menard, Public Relations

Local 1000 of CUPE. OHEU members include nuclear plant operators and all atomic radiation workers.

Ontario Hydro Public Reference Centre

(416) 592-3331

Open to the public, by appointment. Contains many reports about the operation of the company including Significant Event Reports filed with the AECB.

Science Information Sources (SIS)

(416) 425-5613

A non-profit service which refers reporters to a number of scientists who can give comment on a variety of issues. It is run by the Canadian Science Writers Association.

United States Council for Energy Awareness

(212) 599-1881—Media Relations (New York Bureau)
(202) 293-0770—Media Relations (Washington, D.C.,
head office)

A non-profit industrial association of American utilities, nuclear suppliers, labor unions, universities, financial institutions, mining and milling companies and foreign government organizations.

In 1987, the Atomic Industrial Forum (AIF) was split into the Council for Energy Awareness, which provides information to the public and industry on the peaceful applications of nuclear energy, and the American Nuclear Energy Council, which lobbies for nuclear power.

United States Office of Technology Assessment

(202) 226-2115

The office helps Congress anticipate and plan for the consequences of technology. Provides an independent and objective source of information about the impacts, both beneficial and adverse, of technological applications and identifies policy alternatives for technology-related issues.

Publications

Bulletin of the Canadian Nuclear Society.
Ed. Jatin Nathwani.

To subscribe call (416) 977-7620.

Canada's Nuclear Non-Proliferation Policy.

Ottawa: External Information Programs Division, Department of External Affairs, 1985.

Canadian Radiation Protection Association Bulletin.

To subscribe call (613) 237-3392.

Control: An Introduction to the Atomic Energy Control Board.

Ottawa: AECB Office of Public Information.

A magazine explaining the philosophy and various aspects of Canada's regulatory policy in separate, easily understandable articles.

Crouch, Edmund A.C. and Richard Wilson.
Risk/Benefit Analysis.

Cambridge, Massachusetts: Ballinger Publishing Company, 1982.

Detailed but easy-to-understand treatment of the issue by two of its foremost researchers. (Wilson, a Harvard University physics professor, is author of the table on page 64 of this publication.)

Eggleston, Wilfred. **Canada's Nuclear Story.**

Toronto: Clarke Irwin and Co. Ltd., 1965.

Detailed explanation of Canada's contribution to the Manhattan project and the subsequent peaceful development of nuclear power. With excerpts from the letters and diaries of leaders of the day, it is a "good read".

Electric Power in Canada.

Ottawa: Electrical Energy Branch, Energy, Mines and Resources Canada. Available from Ann Moisey, (613) 995-1118 ext. 230.

Published every August, it offers an excellent review of the ownership, structure and operations of Canada's electric utilities. Explains the different regulatory environments under which they operate. Gives production and consumption statistics from the previous calendar year.

The Energy Statistics Yearbook, 1985.

New York: United Nations, 1987.

A comprehensive collection of international energy statistics prepared by the United Nations Statistical Office. Each volume records data from two years before.

Interfaith Program for Public Awareness of Nuclear Issues Report

Toronto: 1985.

Chaired by Rabbi Arthur Bielfeld, Chairman of Energy Probe, the investigating panel was composed of members of the Anglican Diocese of Toronto, the Baha'i Community of Canada, the Jewish Community of Toronto, the Roman Catholic Archdiocese of Toronto, the United Church of Canada Toronto Conference. The final report is in the Ontario Hydro Public Reference Centre (416) 592-3331.

Leclerq, Jacques. **The Nuclear Age**

Paris: Hachette, 1986.

A glossy coffee-table book by the Senior Vice President and Group Manager of Nuclear and Fossil Generation for Electricité de France. Leclerq is responsible for more nuclear plants than anyone in the world. He gives a readable and comprehensive view of the history, technology and future possibilities of the atom. Through reproductions of graffiti and modern and classical art, Leclerq boldly puts nuclear power in context with man's achievements through the ages.

Lyon, Robert and Marvis Tutiah. **Nuclear Fuel Waste Management**

Pinawa: AECL Whiteshell Nuclear Research Establishment.

A good explanation of all aspects of the fuel disposal research underway at Whiteshell in Manitoba.

McGaw, James. **How Safe? Three Mile Island, Chernobyl and Beyond**

Toronto: Stoddart, 1987.

McGaw, a York University physics professor, has written an excellent general introduction to nuclear energy. While he is especially good in his coverage of the effects of nuclear accidents, his coverage of the Chernobyl accident has suffered from what seems to be a rushed publication schedule. Written in a witty and erudite style.

The Nuclear Waste Primer: A Handbook for Citizens

The League of Women Voters Education Fund.
New York: Nick Lyons books, 1985.

Clearly answers the central questions about the handling and disposal of hazardous radioactive materials. Tips for citizens on making their point to government may be useful, even though designed for the American political system.

Radiation: Doses, Effects, Risks

Nairobi: United Nations Environment Program, 1985.

Excellent, easy-to-read, thorough overview of everything the title promises.

Silver, L. Ray. **Fallout from Chernobyl**

Toronto: Deneau, 1987.

A freelance writer with a 50-year journalistic career, Silver has written a readable, unapologetically personal, empassioned polemic on the Chernobyl accident and the larger questions of public responsibility in the nuclear age. All energy costs, Silver says, and nuclear power is still the best deal.

Snell, V.G. **Safety of CANDU Nuclear Power Stations**

Mississauga: AECL Public Affairs Office, Sheridan Park Research Community.

Contains a good explanation of the safety philosophy underpinning the nuclear industry: "Nuclear energy is one of the few industries which has had during its development and deployment an extensive risk assessment" (p. 7). Can be ordered through AECL, (416) 823-2480 or (613) 237-3270.

Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident

Vienna: International Nuclear Safety Advisory Group, Safety Series No. 75—INSAG-1, International Atomic Energy Agency, 1986.

The authoritative explanation of what happened by the best nuclear experts in the world. Most major libraries should have it or be able to get it. The IAEA is a United Nations organization.

Unsworth, G.N. **Decommissioning of CANDU Nuclear Power Stations**

Mississauga: AECL Public Relations Office, Sheridan Park Research Community, 1979.

Easy-to-read overview of the combinations of methods available. Can be ordered through AECL, (416) 823-2480 or (613) 237-3270.

Glossary/Index

Glossary/Index

Glossary/Index

AC power
The electricity generated from an alternating generator, so that the direction of the electric current reverses, or alternates, each time a different magnetic pole is passed. This is the kind of electricity Ontario Hydro generates, **76**

AGR
Advanced gas cooled reactor, uses enriched uranium fuel, graphite moderator, the heat transfer system uses carbon dioxide gas, **70, 72**

AECB
The Atomic Energy Control Board. It was created under the Atomic Energy Control Act, 1946, to ensure strict federal control over all development and use of radioactive and related material and equipment for reasons of national and international health and security, **19-22, 23, 33**

AECL
Atomic Energy of Canada Limited. It was created as a Crown corporation on April 1, 1952, to develop nuclear technology for peaceful uses.

ALARA principle
In the philosophy of nuclear safety, risks should be maintained "As Low As Reasonably Achievable," economic and social factors being taken into consideration.

activity
The rate at which a radioactive substance is disintegrating, measured in becquerels or curies, **57**

adjuster rods
Vertically-mounted rods which can be moved into and out of the reactor core to absorb more or fewer neutrons and so to regulate neutron power, **11, 39**

alpha radiation
Also known as alpha rays, it is a kind of particulate radiation, essentially, a helium nucleus. It can be stopped by a sheet of paper or the outer layer of human skin, **55, 61**

annulus
The carbon dioxide gas-filled space between the pressure tube and the calandria tube. The gas is circulated and monitored for moisture, **9**

atom
The smallest unit of an element that maintains the properties of the element, **50**

BWR
Boiling water reactor. It uses enriched uranium fuel. The same light water system moderates the reaction, is heated to boiling in the core and supplies steam directly to the turbine, **70, 73**

becquerel (Bq)
Système Internationale unit of measurement for the rate of decay of a radioactive substance.

beta radiation
Also known as beta rays. It is a kind of particulate radiation, essentially, an electron. It can be stopped by a three centimetre (one inch) thickness of wood, **55, 61**

BEIR
The Committee on the Biological Effects of Ionizing Radiation, U.S. National Academy of Sciences.

breeder reactor
A reactor which makes more fuel than it consumes, **70, 71, 72**

CANDU
Canada Deuterium Uranium reactor, runs on natural uranium, with a heavy water moderator and heat transport system, **1, 9a, 9-17, 70, 73**

calandria
In the CANDU reactor, a large stainless-steel tank which houses the fuel channels and the heavy water moderator, **9**

calandria shielding
In the CANDU reactor, the thick-walled concrete and/or steel structure which contains the calandria, **9**

calandria tube
In the CANDU reactor, the Zircaloy-2 tube inside which the pressure tube fits, **9, 36**

cask
Specially-designed AECB-licensed container used to transport radioactive materials, **22**

Cobalt-60
Radioisotope used for sterilization and cancer treatment, manufactured in CANDU reactors, **39**

coulomb/kg (C/kg)
Système Internationale unit for the roentgen.

congenital defect
Defect which occurs in the womb or at birth, not passed on to subsequent generations.

constant dollars
An expression of what it would cost if one were to build an existing plant today—the actual construction costs are escalated to account for inflation.

containment
The system which ensures harmful amounts of radiation don't get out of the station. In Ontario Hydro's CANDU reactors it consists of the reactor buildings/vaults, a vacuum building and air filtration system, **15, 16, 17**

coolant system
See heat transfer system.

core
The core of the reactor is the most radioactive part of the reactor, everything inside the calandria.

cosmic radiation
It is composed of various subatomic particles—protons, neutrons, alpha particles, parts of the nuclei of carbon, nitrogen and oxygen atoms, which constantly bombard the earth from outer space, **59**

creep
Metals bearing heavy loads tend to creep, or become thinner and longer, over time, from the weight they are carrying. In pressure tubes, this tendency is exacerbated by the neutron bombardment and high temperatures the tubes endure. Creep manifests itself in three ways in pressure tubes: they elongate, they increase in diameter and they sag, growing closer to the calandria tube, **35, 36**

critical organ
The organ of the body which metabolizes a particular nutrient, or similar radioisotope, **60, 61**

criticality
A state at which the rate of production of neutrons in a reactor core is precisely equal to the rate of loss of neutrons (birth rate = death rate). Also, the point in starting of a reactor at which a nuclear reaction is sustained, **69**

Glossary/Index

curie (Ci)
The unit for measuring the rate of radioactive decay. It is being replaced by the becquerel under the Système Internationale, **57, 94**

current
Electric current, the movement of electrons in a conductive metal, **76, 77**

daughters
Decay products of a radioisotope.

decay
The process whereby a radioactive element changes into another element, releasing alpha, beta and/or gamma radiation, **56, 57**

decay path
The sequence of radioisotopes into which a particular radioisotope decays, **56**

decay heat
The heat produced in reactor fuel after the chain reaction has been stopped or the fuel has been removed from the reactor. It is the heat from the decaying fission products in the fuel.

decommissioning
Safely closing a nuclear station at the end of its service life, **43, 45**

deuterium oxide
Heavy water D_2O, deuterium is an isotope of hydrogen. See heavy water.

direct cycle
The kind of heat transport system in some nuclear reactors, where the heat transfer fluid boils into steam in the core, **69, 70**

distribution system
In Ontario, the 100,000 kilometres (62, 138 miles) of lines which carry electricity at less than 50 kilovolts,

dollars-of-the-year
The total of each year's costs during the construction period. There is no provision for inflation. This total is the most frequently used number when speaking of the cost of building an Ontario Hydro facility.

dose
Radiation exposure.

dosimeter badges
Patches of radiation-sensitive material atomic radiation workers wear to keep track of the amount of radiation to which they are exposed.

dousing tank
Tank suspended in the roof of the vacuum building of a CANDU reactor which contains tonnes of water which would enter the building during an accident situation.

electrical power (e)
The amount of the reactor's heat which can be utilized to generate electricity. Typically, a reactor's electrical power is about 30 per cent of its thermal power, **69, 76**

electromagnetic radiation
Energy travelling through space as waves, **51-53**

electron
Negatively-charged particle orbiting around the nucleus of an atom, **50, 55**

element
Any substance that cannot be separated into different substances except by radioactive decay or nuclear reactions. All matter is composed of elements.

emergency core coolant injection system
In the CANDU, an arrangement of tanks, pumps and valves which would provide large volumes of ordinary water to a reactor core in the event of a leak in a reactor's primary heat transport system, **15, 23, 33**

endfittings
Stainless steel tubes joined to each end of the pressure tubes. They support the pressure tubes, have connections for coolant piping and are closed by removable stoppers to allow fuel changing.

energy
See megawatt-hour.

fast neutron
A neutron ejected from a fissioning atom, at an average speed of 20,000 kilometres (12,400 miles) per second. See "fission", and "breeder reactors", **66, 68, 71**

feedwater
Water supplied to the boilers of a steam plant.

fission
The splitting of uranium atoms, **65**

fission products
Radioisotopes created in nuclear fuel by the breakup of uranium atoms during the operation of a reactor.

flux
In a nuclear reactor, the density of free neutrons in the core, **11, 69**

flux shaping
Controlling the density of free neutrons in the core with adjuster rods, **11**

frequency
The number of complete cycles of an electromagnetic radiation or electric current which occur in a second, **51, 76**

fuel
Typically, a ceramic rather than metallic form of uranium—natural uranium in the CANDU and GCR, enriched in other systems, **9, 14, 41, 45, 67, 71**

fuel channel assembly
In the CANDU, the pressure tube, annulus system, calandria tube and endfittings, **9, 35-37**

fuel enrichment
Increasing the proportion of Uranium-235 above the natural concentration of 0.7 per cent, **1, 67**

fuel handling system
In the CANDU, the remote-controlled machines and associated equipment (conveyors, etc.) which load new fuel and remove used fuel from an operating reactor, **14**

GCR
Gas cooled reactor, uses natural uranium fuel, graphite moderator and carbon dioxide gas as the heat transport medium, **70, 73**

gadolinium
A strong neutron absorber sometimes used to regulate reactor power in the CANDU. It is also used in the second fast shutdown system, **11, 15**

gamma ray
The most penetrating electromagnetic radiation, **53, 55, 61**

garter springs
In the CANDU, spacers which hold the pressure tube from the calandria tube, **9, 35-38**

genetic defect
Affecting hereditary features contained in specific genes and so affecting subsequent generations.

gray (Gy)
Système Internationale unit for the rad.

half-life
The time it takes for half the atoms of a given sample of an isotope to decay, **56, 57**

health physics
The scientific discipline which studies health hazards from ionizing radiation and develops ways of minimizing them.

heat sink
Heat absorber; the moderator would absorb heat from the fuel during a loss-of-coolant accident in which the main cooling system and the emergency cooling system didn't operate, **17**

heat transfer system
Like "coolant system", it is a generic name for the system which carries heat from the fuel, **69**

heat transport system (primary)
In indirect cycle reactors, such as the CANDU, the system which takes the heat from the fuel and transfers it to a secondary, boiling water circuit which provides steam to the turbine generator, **10, 12**

heavy water
Deuterium oxide, D_2O, the moderator and heat transport fluid used in the CANDU reactor, See page **68**, making heavy water; see also moderator and heat transport system.

hertz (Hz)
Expresses the number of back and forth cycles of electron movement per second; 60 Hz power means there are 60 cycles per second, **52-53, 76**

hydride blisters
Blisters which can occur on pressure tubes which have absorbed a high level of deuterium from the heavy water and have sagged into contact with their calandria tube, **36, 37**

hours electric (he)
The electrical output of a nuclear reactor over time. The electrical output is one third the reactor's thermal power. Generally, when one speaks of "megawatt-hours", one means MWhe, whether or not it is written that way.

IAEA
International Atomic Energy Agency. A United Nations agency which conducts on-site inspections of nuclear facilities in the western world, sets international standards for operation and safety of nuclear facilities and facilitates the exchange of scientific and engineering data.

ICRP
International Commission on Radiological Protection. Founded in 1928, it is an independent non-government expert body that establishes radiation protection standards followed by most countries in the world, **23, 61**

in-service date
For accounting purposes, the official date at which an Ontario Hydro generating station begins commercial electricity production. The station actually begins producing electricity before this date.

indirect cycle
The kind of heat transport system in most nuclear reactors, where the fuel's heat is transferred to water or gas in one circuit which then causes water in another separate circuit to boil, **69, 70**

installed capacity
It refers to the AECL-approved continuous output of a nuclear reactor's generator. It can also be used to mean the continuous output of any generator or the sum of all units' installed capacity in the electrical system.

ionizing radiation
Radiation that causes atoms to gain or lose protons and so develop a net electrical charge. When ionization occurs in tissue, it can change the chemical makeup of the tissue and lead to cancer and congenital malformation and possibly, to genetic damage, **58, 62**

irradiation
Exposure to radiation, **58**

isotopes
Isotopes of an element are atoms of an element with the same number of protons but different numbers of neutrons. All isotopes of an element have the same chemical properties (ie., they will combine with the same substances) but have slightly different physical properties (ie., one will have greater mass than another). Most isotopes are man made and are radioactive. Radioactive isotopes are called radioisotopes.

LGR
Light water-cooled graphite-moderator reactor. It uses enriched uranium fuel, a graphite moderator, and the light water heat transfer fluid boils in the core, **70, 72**

LMFBR
Liquid metal fast breeder reactor. In operation, it produces plutonium, creating more fuel than it consumes. The reactor uses enriched uranium fuel, liquid sodium as a heat transfer fluid and there is no moderator, **70, 71, 72**

light water
Ordinary water. It is used as a heat transport fluid and moderator in various reactor designs, **68, 70, 71**

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linear theory
The theory used to calculate the health effects of low level radiation exposure: the likelihood of an effect occuring is directly (linearly) proportional to the exposure, **63**

megawatt (MW)
Usual measure of the electrical output at any one point in time of a nuclear reactor.

megawatt-hour (MWh)
The output of a nuclear reactor over time: a one megawatt output over 24 hours is 24 megawatt-hours (as is 24 megawatts for one hour). See "hours electric".

moderator
In a nuclear reactor, it is the substance which slows down the fast-moving neutrons to "thermal" velocities so they are more likely to cause subsequent fissions, **10, 12, 68**

moderator dump
"Dumping"—quickly draining—the moderator is one way to shut down early models of the CANDU reactor, **17**

natural background radiation
The sum of unavoidable, low-level radiation from a number of sources all around us—buildings, the earth, the sun, etc., **59, 62**

neutron
A particle in the nucleus of an atom which has no charge, **50**

neutron flux
See flux.

neutron radiation
A very penetrating form of radiation, made up of neutrons ejected from the nuclei of uranium atoms during nuclear fission and created in particle accelerators. Neutron radiation induces radioactivity, **55, 58, 61**

noble gases
Xenon, argon, krypton, neon, helium. They are chemically-inert gases. Radioisotopes of the noble gases are created during the operation of a nuclear reactor, **17, 25, 60**

Nuclear Liability Act
Federal legislation in Canada to regulate accident insurance for nuclear generating stations, **47**

nuclear payback agreement
An agreement between Ontario Hydro, the province of Ontario and AECL to cover the cost of building and operating Pickering 1 and 2, the first large-scale nuclear reactors in Canada, **46**

PWR
Pressurized water reactor. It uses enriched uranium fuel. The same pressurized light water system moderates the reaction and transfers heat to the boilers, **70, 73**

particulate radiation
Energy travelling through space with particles, **55**

photon
A measurable quantity of electromagnetic energy, almost like a particle, **51**

pile
Original name for a nuclear reactor. It was adopted because the first man-made reactor was literally a "pile" of graphite blocks. The term is now used principally in the U.K.

poison
Name given to any strong neutron-absorbing material. Ontario Hydro uses boron and gadolinium, to help regulate the reactor power. Xenon, another poison, or neutron absorber, is produced in the fuel during CANDU reactor operations, **11, 15**

poison outage
Occurs when the reactor trips and cannot be restarted within about half an hour: the xenon levels in the fuel build up to the extent that so many neutrons are absorbed that the number of fissions falls below the level needed to sustain a fission reaction. The reactor cannot be restarted for 36 hours, because it takes that time for the xenon to decay to the extent that the reactor can restart.

power
See megawatt.

pressure tube
In the CANDU reactor, a tube which holds the fuel, **9, 35-38, 81a, 81, 82, 83**

process systems
The systems which are necessary for the routine operation of a nuclear reactor.

proton
Positively-charged particle in the nucleus of an atom, **50, 55**

REFAB
Repositioned Endfittings and Bearings, a maintenance program likely to be performed on some CANDU reactors where the design allowance was not great enough to accommodate tube creep, **35**

RMBK
See LGR.

rad
An acronym for "radiation absorbed dose": it is the measure of the amount of energy the ionizing radiation deposits per gram of tissue, **61**

radioactive decay
See decay.

radioactivity
The spontaneous disintegration of the nucleus of an atom by expulsion of particles. It can be accompanied by electromagnetic radiation. Solids, liquids or gases can be radioactive, **56, 57**

radiation
Energy moving through space as waves or particles, **49, 50, 51-64**

radioiodine
Radioactive iodine. There are several radioisotopes of iodine produced during normal operation of a reactor, **17, 25, 26, 57, 60**

radioisotope
See isotope.

radon daughters
The decay products of radon, they are significant contributors to normal background levels of radiation, **59**

reactor power
The number of free neutrons in the core and so, the number of fissions, the heat they generate.

reactor regulating system
The computer system which regulates the reactor by controlling the reactor power, through the addition of metal or water-filled rods or a poison to the reactor core to absorb neutrons, **11, 69**

rem
Roentgen equivalent man: the unit used to measure the relative effect of rads of different ionizing radiations on different body tissues, **23, 24, 25, 26, 61, 62**

retrofitted
Backfitted: an improvement made to an operating plant.

retubing
Replacing the pressure tubes in a CANDU nuclear reactor, **35-38, 82, 83**

roentgen (R)
The unit for measuring a quantity of ionizing radiation.

safety systems
Independent systems whose sole function is (a) fast shutdown; (b) emergency fuel cooling; (c) containment of radioactive material released from reactor fuel. In the CANDU design, the safety systems are independent of the process systems and independent of each other. They are: Shutdown System No. 1 and 2, the emergency core coolant injection system and containment system. They do not function during normal operation of the reactor, **15-17**

sag
In the CANDU, the term describes the phenomena of pressure tube sagging into contact with the calandria tube and the whole fuel channel sagging, **35**

shutdown system no. 1
In the CANDU, a rod-drop system which can shut the reactor down within two seconds, **15**

shutdown system no. 2
In the CANDU, a fast-shutdown system which uses gas pressure to inject a gadolinium nitrite solution through nozzles into the moderator, **15**

sievert (Sv)
Système Internationale unit for the rem.

sump
In a CANDU reactor, it is a pump system which under routine conditions, collects any drips from the reactor's piping system and under emergency conditions, will collect and recirculate moderator water, heat transport water or emergency coolant water through the reactor so that the fuel does not overheat.

thermal neutrons
Neutrons moderated to a speed of 2,220 metres (7,300 feet) per second. This is the speed at which they are most likely to cause fission, **66, 68**

thermal power (th)
The heat produced in the core of the reactor. About one third of it can be utilized for electricity generation.

thyroid blocking
Taking potassium iodide (KI) or potassium iodate (KIO_3) pills to counter the effect of radioiodine exposure. By increasing the amount of iodine in the blood, the amount of radioiodine is diluted, so less of it will be absorbed by the thyroid. Any iodine—radioactive or not—not used by the thyroid is passed in the urine in two or three days, **60, 61, 95**

transformer
The apparatus which increases or decreases the voltage of electricity, **77**

transmission system
In Ontario, 15,546 kilometres (9,660 miles) of high voltage (115 and 230 kV) and extra-high voltage (500 kV) electric lines, **77, 78**

transmutation
See decay.

tritium
An isotope of hydrogen which is an unintended byproduct of the operation of a CANDU reactor: it builds up in heavy water, **24, 39, 60**

tritium removal facility (TRF)
At Darlington, it will remove tritium from heavy water transported from all of Hydro's operating plants, **7, 39, 83**

UNSCEAR
United Nations Scientific Community on the Effects of Atomic Radiation.

vacuum building
A thick-walled negative-pressure building which would contain any radioactivity in an accident situation for at least 24 hours, **15, 16, 17**

vapor dryer
A dehumidifier; part of the air filtration system in the CANDU reactor, it removes any heavy water vapor from air in the reactor before it is vented to the atmosphere.

voltage (v)
The "pressure" under which electricity is transmitted; analogous to water pressure, **77**

wheeling power
Sending one utility's electricity through another's transmission lines to the first utility's customer, for a fee, **79**

Zircaloy-2
The alloy originally used in pressure tubes in Pickering 1 and 2, since replaced. Used in calandria tubes in all Ontario Hydro reactors, **9, 37**

zirconium-niobium
The alloy now used in all Ontario Hydro pressure tubes, **9, 37**

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